GPS MEASUREMENTS OF THE GEOTECTONIC RECENT MOVEMENTS IN EAST SLOVAKIA

Prof. Vladimir SEDLAK, Slovakia

Key words: GPS**,** 3D transformations, topocentric coordinate system, free adjustment, adjustment with constraints, deformation teststatistics.

ABSTRACT

The paper deals with transformation procedures observed *GPS* (*Global Positioning System*) data from the World Geodetic System *WGS-84* into the national geodetic grid datum *S-UTCN* (*System of United Trigonometric Cadaster Network*) and *Baa*.(*The Baltic Sea after adjustment*). *GPS* measurements are situated into the geodetic network in the Košice-Valley for a purpose of deformation surveying geotectonic recent movements in the East-Slovak regions. Adjustment with constraints and free adjustment are applied at determining coordinates of the geodetic network points.

Transformation from *WGS-84* into *S-UTCN* is the most frequently by means of using the 7-element Helmert transformation with using three identical points. Geodetic network was adjusted by two ways. In a case when datum parameters are absolutely accuracy then an adjustment with constraints is considered; in a case when datum parameters are determined with a concrete accuracy, what has also an influence on an accuracy of adjusted parameters except on measured accuracy, then a free adjustment is considered.
The *GPS* measurements are realised on points of the geodetic network (*GN*) localised in the Kosice-Valley (Slovakia). The aim of these measurements is determining recent geotectonic movements in the urban agglomeration of Kosice-city. 3D coordinates of the network points determined from satellite navigation present a realisation result of the solved scientific project at the Department of Geodesy and Geophysics of the Technical University of Kosice since 1997.

GPS measurements are periodically realised twice a year (spring and autumn). Altogether, 17 points of *GN* are measured by means of using the *GPS* static method. A priority of the chosen static method for our measurements is above all a high accuracy in determining point position, which is conditioned by longer period of measurement on a determined point (cca 45 minutes). The determined *GN* points are solved by double *GPS* vector technology always regarding two reference points, i.e. three *GPS* receivers are used for measurements. These points are placed so that the territories in which some geotectonic movements are presupposed according to geologists. The main tectonic fault in the Kosice-Valley, according to which two expressive geological faults of the Earth ground blocks should move, is assumed in the north-south direction along the river Hornad. The secondary tectonic faults of smaller extent are in the direction perpendicular to the Hornad fault, i.e. in the east-west direction. These secondary tectonic faults are mutually parallel.

Three double-frequency *GPS* receivers Sokkia GRS 2100 were used to measurement. Adjustment of observed data was realised by the firm software Prism ver 2.1 Sokkia. Coordinates of all points in *GN* were transformed from *WGS-84* into a plane coordinate system *S-UTCN*, which is obligatory coordinate system for realisation of geodetic works in Slovakia. The non-linear rotary matrix method was applied to the adjustment. After transformation, the coordinates were consecutively adjusted by an adjustment with constraints.

For a purpose of deformation consideration in the monitoring network the coordinate differences are subjected to the teststatistic hypotheses. A size of deformations is presented by the deformation vectors on the individual network points. Modelling deformations in the Kosice-Valley is based on GIS data by means of using the MicroSoft and Kokes software.

INTRODUCTION

The *GPS* measurements are realised on points of the geodetic network (*GN*) localised in the Kosice-Valley (Slovakia) (Fig. 1). The aim of these measurements is determining recent geotectonic movements in the urban agglomeration of Kosice-city (Sedlak et al., 1998). 3D coordinates of the network points determined from satellite navigation present a realisation result of the solved scientific project at the Department of Geodesy and Geophysics of the Technical University of Kosice since 1997.

GPS MEASUREMENTS IN THE KOSICE-VALLEY

GPS measurements are periodically realised twice a year (spring and autumn). Altogether, 17 points of *GN* are measured by means of using the *GPS* kinematic method. Priority of the chosen kinematic method for our measurements is above all a high accuracy in determining point positions which is conditioned by the period of measurement on a determined point (cca 5 minutes). The accuracy of the kinematic methods is same like at the static method (Hofmann-Wellenholf et al., 1993; Seeber, 1993; Leick 1995). The determined *GN* points are solved by double *GPS* vector technology always regarding two reference points, i.e. three *GPS* receivers are used for measurements. These points are placed so that the territories in which some geotectonic movements are presupposed according to geologists. The main tectonic fault in the Kosice-Valley, according to which two expressive geological faults of the Earth ground blocks should move, is assumed in the north-south direction along the river Hornad. The secondary tectonic faults of smaller extent are in the direction perpendicular to the Hornad fault, i.e. in the east-west direction. These secondary tectonic faults are mutually parallel (Jacko, 1997).

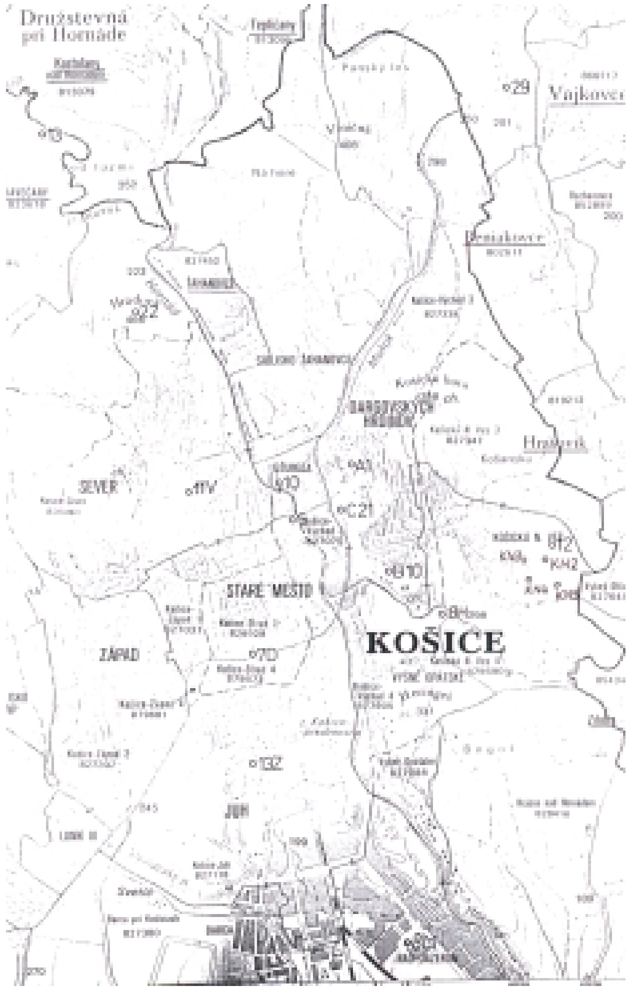

Figure1. Positioning the Kosice-Valley *GN* (1:100 000).

Three double-frequency *GPS* receivers Sokkia GRS 2100 were used to measurement. Adjustment of observed data was realised by the firm software Prism ver 2.1 Sokkia. Coordinates of all points in *GN* were transformed from *WGS-84* into a plane coordinate system *S-UTCN*, which is obligatory coordinate system for realisation of geodetic works in Slovakia. The non-linear rotary matrix method was applied to the adjustment (Melicher and Flassik, 1998). After transformation, the coordinates were consecutively adjusted by an adjustment with constraints.

COORDINATE TRANSFORMATION OF THE GN POINTS FROM WGS-84 INTO S-UTCN

System *NAVSTAR GPS* uses *WGS-84* with the purpose of expressing the position anywhere in the earth and space. The reality that the *GPS* system determines a position in global dimensions is its priority. However, the disadvantage for surveying is its limitation in a plane rectangular system that is our national geodetic grid *S-UTCN* (system *S*).

Transformation of coordinates from WGS-84 into a topocentric horizontal system

The coordinate axes $(X, Y, Z)_{\mathrm{WGS\text{-}84}}$ with an origin in the centre of ellipsoid create the system $S_{WGS\text{-}84}$ (Fig. 2). The coordinate axes X'', Y'', Z'' create the topocentric horizontal coordinate system S'' (Melicher and Flasik, 1998; Hurcikova, 1998). Its origin lies in the point *D*. Point *D* is one point belonging to points of a local network. This point is situated approximately in its centre. To assume that the geodetic horizon in *D* is a parallel plane to *S-UTCN* is only possible in a case of local *GN* with a small dimension (if distances between network points are not longer than some units of kilometres). Table 1 presents coordinates of the point *D*. Axes X'' and Y'', which lie in a geodetic horizon of the point *D*, while the axis X'' is oriented into the south branch of a meridian. The axis $+Z''$ lies in a normal line and is directed into the geodetic zenith and the axis $+Y''$ creates with the mentioned axes a left-hand system.

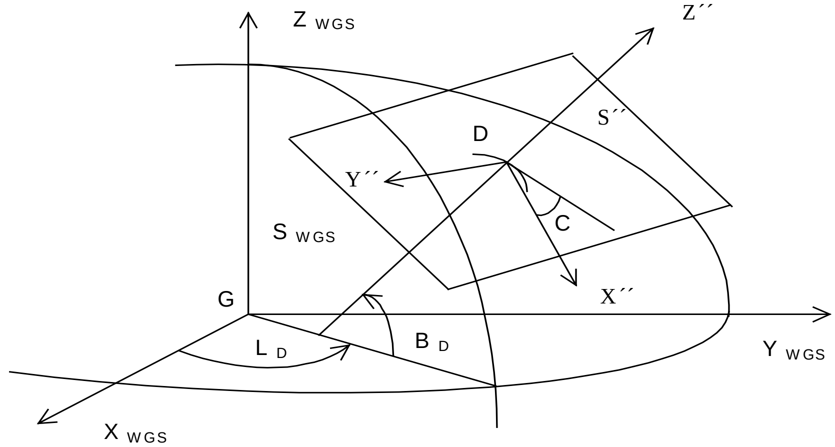

Figure 2. $S_{WGS\text{-}84}$ and S''.

Table 1. Coordinates of the point *D* in *WGS-84* and *S-UTCN*.

	WGS-84 [m]	*S-UTCN* [m]
X	3 927 761.7721	1 237 997.5879
Y	1 528 741.4010	262 066.5466
Z	4 771 351.2319	212.0736

Ellipsoid latitude φ_D = 48° 44´ 7.12´´
Ellipsoid longitude λ_D = 21° 16´ 21.22´´
Meridian convergence C = 2° 39´ 42.89´´

Transformation of coordinates from the system $S_{WGS\text{-}84}$ into the system S'' is a possible according to the following equation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S''} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} .\boldsymbol{R}_Y(90^\circ - \boldsymbol{\varphi}_D).\boldsymbol{R}_Z(\boldsymbol{\lambda}_D). \begin{bmatrix} X - X_D \\ Y - Y_D \\ Z - Z_D \end{bmatrix}, \qquad (1)$$

where index *D* means that the tangent point is considered, $_D$,($_D$) is ellipsoidal geocentric latitude, (longitude) of point *D*, $\boldsymbol{R}_Y$ (*90°* - $_D$), $\boldsymbol{R}_Z$($_D$) are non-linear rotation matrices according to the following equations (Melicher et al., 1993)

$$\boldsymbol{R}_Y(90^\circ - \varphi_D) = \begin{bmatrix} \cos(90^\circ - \varphi_D) & 0 & -\sin(90^\circ - \varphi_D) \\ 0 & 1 & 0 \\ \sin(90^\circ - \varphi_D) & 0 & \cos(90^\circ - \varphi_D) \end{bmatrix}, \tag{2}$$

$$\boldsymbol{R}_Z(\lambda_D) = \begin{bmatrix} \cos(\lambda_D) & \sin(\lambda_D) & 0 \\ -\sin(\lambda_D) & \cos(\lambda_D) & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{3}$$

The coordinates of the *GN* points in *WGS-84* are obtained by a convenient adjustment of measurements, which were realised by the system *NAVSTAR GPS*. The right-hand system is changed into left-hand which is preferred in geodesy. This change can be reached by multiplying a diagonal matrix with the diagonal (*1, -1, 1*). The point *D* has the coordinates $(X, Y, Z)^T = (0, 0, 0)^T$ in the system *S´´*.

The system *S´´* is also possible to obtain by using the following equation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S''} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} . \boldsymbol{R}_Y(90^\circ - \boldsymbol{\varphi}_D) . \boldsymbol{R}_Z(\boldsymbol{\lambda}_D) . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS-84} + \begin{bmatrix} -\Delta X \\ 0 \\ -\Delta Z \end{bmatrix}, \tag{4}$$

where ΔX is distance of the normal from the centre of the ellipsoid, ΔZ is a displacement of the plane *XY* into the point *D* in the normal direction.

In the sense of Figure 3, the quantities ΔX and ΔZ are derived according the equations

$$\begin{aligned} \Delta X &= N(\varphi_D) e^2 \sin\varphi_D \cos\varphi_D , \\ \Delta Z &= N(\varphi_D) - \Delta X \, tg\, \varphi_D + H_D , \end{aligned} \tag{5}$$

where *A(* $_D$*)* is the transverse radius of curvature in the point *D*, *e* is the numerical eccentricity, H_D is the ellipsoid height of the point *D*.

A transition between the local and the commonly used national system should be the simplest in their contact point for a purpose of using the state network. It means that the coordinates of the local network should not much differ from *S-UTCN*. It can be reached by turning the system *S´´* in the point *D* about the meridian convergence *C* (Fig. 2) of *S-UTCN* and by displacement of the origin of the system *S´´* round the rectangular coordinates X_D, Y_D in *S-UTCN*. The mentioned transformation is expressed by the following equation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S'} = \boldsymbol{R}_3(-C).\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S''} + \begin{bmatrix} X_D \\ Y_D \\ h_D \end{bmatrix}_{S-UTCN,Baa} , \tag{6}$$

where $\boldsymbol{R}_Z(-C)$ is the rotation matrix determined by the equation

$$\boldsymbol{R}_3(-C) = \begin{bmatrix} \cos(-C) & \sin(-C) & 0 \\ -\sin(-C) & \cos(-C) & 0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{7}$$

and h_D is the over-sea level height of the point D in the Baltic sea elevation system after adjustment (*Baa.*).

In this way we obtained the topocentric horizontal coordinate system whose the coordinate axes X', Y' lie in the geocentric horizon of the point of normal intersection of the point D with the geoid. Because the point D has the coordinates $(0,0,0)^T$ in the system S´´, then this point will obtain identical coordinates with the coordinates in *S-UTCN* by adding the vector $(x_D,y_D,h_D)^T_{S-UTCN}$.

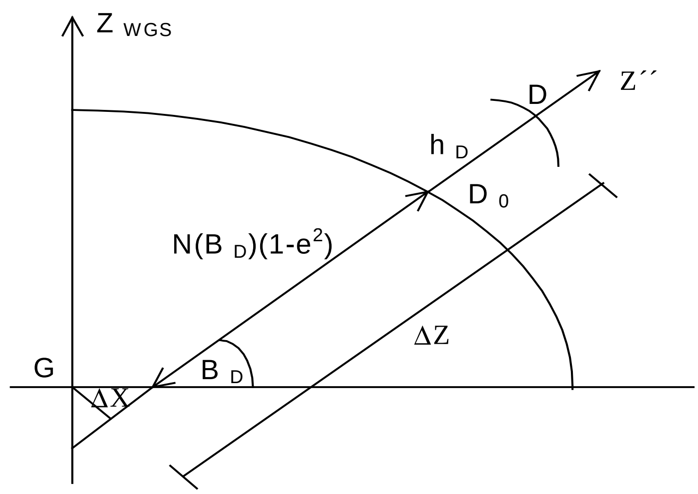

Figure 3. Transformation from the geocentric into the topocentric system.

Transformation of coordinates into the local coordinate system

It is not possible to calculate directly the values of elements which would harmonise with the values measured in a terrain using the coordinates of points in the system *S´*. These coordinates are influenced by the Earth curvature and also by a relative difference in elevation of point over the horizon plane. Regarding to a network dimension, we can substitute the ellipsoid by the reference sphere whose radius is equal to the mean radius of the Earth curvature R in the point D according to the equation

$$R = \sqrt{M(\varphi_D)N(\varphi_D)}, \tag{8}$$

where M is the meridian and N the transversal radius of curvature of the ellipsoid, which are described by the following equations (Mervart and Cimbalnik, 1997)

$$M(\varphi_D) = \frac{a\left(1 - e^2\right)}{\left(1 - e^2 \sin^2(\varphi_D)\right)^{3/2}}, \tag{9}$$

$$N(\varphi_D) = \frac{a}{\left(1 - e^2 \sin^2(\varphi_D)\right)^{1/2}}, \tag{10}$$

where a and e^2 are the constants of the used ellipsoid (the semimajor axis and square of the 1st numerical eccentricity) (the Bessel ellipsoid).

An influence of the difference of elevation is possible to eliminate if the coordinates *X´*, *Y´* are reduced into the intersection of the normal with the tangent plane, or with the basic plane. The reduction from a relative difference of elevation is possible to influence significantly by moving the geodetic horizon into the basic plane of *GN* in the height z_0. This height equals to approximate mean elevation value in which geodetic measurements are realised. The reduction of the coordinates *X´*, *Y´* of the *GN* points in the system *S´* into the intersection of the normal with the basic plane equals to a gnomic projection which regarding to the network dimension is considered a conform projection.

The presented method has several priorities. Above all, it is the fact that a high relative accuracy in determining point positions by means of using *NAVSTAR GPS* technology is not lost. Similarly a measurement on one identical point is only enough instead of three identical points, by that a transmission of some errors at the transformation can be reduced. Reductions from elevation and cartographic distortion are needed in *S-UTCN* where only reduction from a relative height or elevation is considered in some local system. This reduction is also minimised by a convenient choice of transformation parameters (Melicher and Flassik, 1998).

Adjustment with constraints of 2D geodetic network

Geodetic networks can be adjusted by two ways. If we consider datum parameters as absolutely accurate and we do not include them into an adjustment process, the adjustment with constraints is considered in this case. In fact that datum parameters are also determined with a concrete accuracy that has an influence on an accuracy of adjustment parameters except for measurement accuracy. In this case a network can be adjusted by a free adjustment with consideration of datum parameters (Mervart, 1994). Regarding the applied confinement adjustment in the Kosice-Valley GN a theoretic procedure of this adjustment is presented, which is the most convenient for our national geodetic grid *S-UTCN*.

The least mean square method (*LMSM*) is chosen as an estimate principle, and the inverse solution is chosen as a mathematical principle, which is a standard procedure in an adjustment of *GN*. After adjustment the position and form of *GN* are changed but the datum point positions are not changed (datum points are considered as absolutely accurate). This fact is presented so that the configuration matrix ***A*** and also the matrix ***N*** of *GN* will be regular; the rank of matrices $h(\boldsymbol{A})=k$, $h(\boldsymbol{N})=k$, where $\boldsymbol{k}$ is a number of determined parameters. For the adjustment the following four vectors and matrices are necessary to be:

$\underset{k,1}{\boldsymbol{C}^{o}}$ is the vector of approximate coordinates of the network points which are calculated from measured quantities and approximate coordinates of the reference points, instead of the coordinates obtained after transformation;

$\underset{n,1}{\boldsymbol{l}^{o}}$ is the vector of approximate values of measured observations which are calculated from the approximate coordinates of the *GN* points on a base of the model equations (i.e. common mathematical equations for calculation of geodetic elements, for example lengths, angles, etc.);

$\underset{n,k}{\boldsymbol{A}}$ is the configuration matrix of *GN*. Terms of this matrix are determined by partial derivatives of the model equations $\boldsymbol{L}$ according to the studied parameters. For a check it is possible to spread this matrix for the datum (object) points too, by this way we can get a global configuration matrix. A sum of the terms in a row of the constructed matrix must be equalled to zero. However, we only consider a submatrix containing the determined points at calculations, where n is a number of measurements and k is a number of the determined parameters;

$\underset{n,n}{\boldsymbol{Q}_{l}}$ is the cofactor matrix of the measured quantities.

It is the matrix in which cofactors of the measured quantities are occurred. These cofactors can be calculated according to the equation

$$q_{l_i} = \frac{\sigma_i^2}{\sigma_o^2}\ , \tag{11}$$

where σ_i^2 is the standard deviation of measurement, while the variance factor σ_0^2 (a priori variance factor) is determined by the equation

$$\sigma_o^2 = \frac{\sum_{i=1}^{n}\sigma_i^2}{n}. \tag{12}$$

Solving equations of the estimate statistic model by means of using *MSM* we will get the following the linear equation

$$\boldsymbol{A}^T.\boldsymbol{Q}_l^{-1}.\boldsymbol{A}.\,d\hat{\boldsymbol{C}} - \boldsymbol{A}^T.\boldsymbol{Q}_l^{-1}.d\boldsymbol{l}=0, \tag{13}$$

where $d\boldsymbol{l}=\boldsymbol{l}-\boldsymbol{l}^o$ is the vector of reduced observations, while $\boldsymbol{l}$ is the vector of the observed quantities and $\boldsymbol{l}^o$ is the vector of the approximate values of the measured quantities.

If we indicate $\boldsymbol{N}=\boldsymbol{A}^T.\boldsymbol{Q}_l^{-1}.\boldsymbol{A}$ and $\boldsymbol{n} = \boldsymbol{A}^T.\boldsymbol{Q}_l^{-1}.d\boldsymbol{l}$, we will get the following equation for the vector of the adjusted coordinate complements $d\hat{\boldsymbol{C}}$

$$d\hat{\boldsymbol{C}} = \boldsymbol{N}^{-1}.\boldsymbol{n}$$

$$d\hat{\boldsymbol{C}} = (\boldsymbol{A}^T.\ \boldsymbol{Q}_l^{-1}.\boldsymbol{A})^{-1}.\boldsymbol{A}^T.\ \boldsymbol{Q}_l^{-1}.d\boldsymbol{l}\ . \tag{14}$$

After adding $d\hat{\boldsymbol{C}}$ to the vector of the approximate coordinates of points we will obtain the adjusted coordinates $\hat{\boldsymbol{C}}$ of points (Tab. 2) according to the equation

$$\hat{\boldsymbol{C}} = \boldsymbol{C}^o + d\hat{\boldsymbol{C}}\,. \tag{15}$$

The quality of the adjusted network is universally characterised by two matrices:

- the cofactor matrix of the estimates $\boldsymbol{Q}_{\hat{C}}$ of coordinates

$$\boldsymbol{Q}_{\hat{C}} = (\boldsymbol{A}^T.\ \boldsymbol{Q}_l^{-1}.\boldsymbol{A})^{-1} = \boldsymbol{N}^{-1}\,, \tag{16}$$

- the covariance matrix of the estimates $\boldsymbol{\Sigma}_{\hat{C}}$ of coordinates

$$\boldsymbol{\Sigma}_{\hat{C}} = s_0^2.\boldsymbol{Q}_{\hat{C}}\,, \tag{17}$$

$$\boldsymbol{\Sigma}_{\hat{C}} = \begin{bmatrix} \sigma^2_{\hat{X}_1} & \sigma^2_{\hat{X}\hat{Y}_1} & & & \\ \sigma^2_{\hat{Y}\hat{X}_1} & \sigma^2_{\hat{Y}_1} & & & \\ & & \ddots & & \\ & & & \sigma^2_{\hat{X}_k} & \\ & & & & \sigma^2_{\hat{Y}_k} \end{bmatrix}, \tag{18}$$

where s_0^2 is empirical variance factor determined by the equation

$$s_0^2 = \frac{\boldsymbol{v}^{\mathrm{T}}.\boldsymbol{Q}_{\mathrm{l}}^{-1}.\boldsymbol{v}}{n-k}\,, \tag{19}$$

in which a numerator expresses the quadratic form of corrections Ω and a denominator expresses the number of superfluous measurements (redundantion of a network). A presumption of better quality of *GN* will increase together with increasing the difference *n-k.* The vector of corrections $\boldsymbol{v}$ is determined by the equation

$$\boldsymbol{v} = \boldsymbol{A}.\ d\hat{\boldsymbol{C}} - d\boldsymbol{l}\,. \tag{20}$$

Table 2. The adjusted coordinates of the *GN* points in *S-UTCN*.

	Autumn 1997			*Autumn 1999*		
	S-UTCN	*Baa.*		*S-UTCN*	*Baa.*	
Point	*X*	*Y*	*H*	*X*	*Y*	*H*
	[m]		[m]	[m]		[m]
29	1 232 352.445	258 830.025	219.398	1 232 352.460	258 830.011	219.387
6	1 237 997.593	262 066.532	212.081	1 237 997.607	262 066.533	212.071
10	1 237 549.022	262 319.756	210.528	1 237 549.025	262 319.768	210.549
22	1 234 955.179	264 129.685	466.150	1 234 955.166	264 129.693	466.169
8H	1 239 477.294	260 026.978	315.799	1 239 477.301	260 026.970	315.814
A1	1 237 378.648	261 318.594	255.320	1 237 378.669	261 318.575	255.351
B10	1 238 862.613	260 850.840	281.508	1 238 862.590	260 850.819	281.547
C21	1 238 055.052	261 451.563	219.404	1 238 055.060	261 451.555	219.385
7D	1 239 951.154	262 718.114	229.253	1 239 951.172	262 718.096	229.212
11V	1 237 635.842	263 468.497	223.750	1 237 635.806	263 468.471	223.707
KN1	1 238 654.533	258 910.911	283.878	1 238 654.548	258 910.925	283.899
KN2	1 238 719.094	258 712.611	297.412	1 238 719.070	258 712.627	297.425
KN3	1 238 720.158	259 175.751	292.020	1 238 720.164	259 175.759	291.991
KN4	1 239 037.024	259 050.728	281.639	1 239 037.035	259 050.739	281.604
KN5	1 238 850.984	258 802.450	271.850	1 238 850.973	258 802.435	271.867

The covariance estimates of the coordinates are situated on a diagonal of the covariance matrix in a direction of individual axes. The adjusted values of the measured terms $\hat{\boldsymbol{l}} = \boldsymbol{l} + \boldsymbol{v}$ are also determined in a frame of an adjustment.

Deformation vector $\boldsymbol{d}$ was estimated by a simple way, i.e. algebraic calculations in rectangular triangles in the plane of *S-UTCN*. Position deformation vector presents deformations in a plane of *X,Y* axes and height deformation vector presents deformations (subsidences) in the Baltic sea level system as a difference between the heights on the *GN* points. Table 3 presents the deformation vectors with standard deviations of the *GN* points. Because all deformation vectors are in limits of the error circles, we did not presuppose any recent geotectonic movements in the Kosice-Valley.

Table 3. The deformation vector $\boldsymbol{d}$ (in position and height) and standard deviations of the *GN* points.

Point	Position $\boldsymbol{d}$ (X ,Y) [m]	Height $\boldsymbol{d}$ (H) [m]	σ_X [mm]	σ_Y [mm]
29	0.024	0.011	5.308	6.698
6	0.014	0.010	4.965	6.842
10	0.012	- 0.021	4.924	7.204
22	0.015	- 0.019	4.970	7.081
8H	0.031	- 0.015	6.187	6.098
A1	0.020	- 0.031	5.104	6.975
B10	0.026	- 0.039	5.682	5.974
C21	0.044	0.019	5.129	6.450
7D	0.021	0.041	4.951	7.548
11V	0.028	0.043	8.221	7.538
KN1	0.011	- 0.021	6.669	5.444
KN2	0.012	- 0.013	5.955	6.078
KN3	0.010	0.029	6.561	5.224
KN4	0.016	0.035	5.991	6.107
KN5	0.017	- 0.01	5.808	6.232

CONCLUSIONS

The results of measurements by *GPS* technology confirm a typical event of using this satellite measurement in *GN* with a spread application in geodesy. The applied kinematic method of *GPS* measurements shows on a high accuracy of satellite measurements which is also acceptable for some other geodetic measurements, for example: a deformation surveying the earth surface and engineering structures. The reached results of the presented transformation procedures refer to the adaptability of transformations from *WGS-84* into the national geodetic grid *S-UTCN* and *Baa*. The chosen confinement adjustment by means of using the Gauss-Markov model is demonstrated as the most suitable mathematical model in an adjustment of *GN* in the Kosice-Valley locality (Hurcikova, 1998). The presupposed possible recent geotectnonic movements in the direction of north-south along the Hornad river are not confirmed.

The paper followed out from the research Project No. 1/7335/20: Deformation modelling geotectonic recent movements in Kosice Valley.

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CONTACT

Assoc. Prof. Vladimir Sedlak, MSc., PhD.
Technical University
Department of Geodesy and Geophysics
Park Komenskeho 19
SK-043 84 Kosice
SLOVAKIA
Tel. + 421 95 6022 916
Fax + 421 95 6336 618
E-mail: sedlak@tuke.sk

BIOGRAPHICAL NOTE

Vladimir Sedlak is associate professor on geodesy and engineering surveying at the Technical University of Kosice, Department of Geodesy and Geophysics, Slovakia. He graduated on mine surveying and geodesy at TU Kosice in 1980. In 1987 he obtained PhD. on mine surveying. He is member of FIG (Commission 4), Presidium ISM and General Assembly CLGE.