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THE USAGE OF GNSS FOR DETERMINATION OF 2D GEODYNAMIC CHANGES OF SKOPJE VALLEY

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ABSTRACT

This paper shows the results of the determination of the geodynamic occurrences present in the territory of the Skopje Valley in the period of 2008-2012, with helpful implementation of modern geodetic methods and technology.
This paper displays the geodetic activities taken over the territory of the Skopje Valley, in order to demonstrate the proper use of modern measuring technology for satellite positioning and optimal coverage of fault structures on this territory.
The paper analyzes the results of two series of GNSS measurements on the geodynamic network of the Skopje Valley made in 2008 and 2012. The comparison of these series of measurements results in certain conclusions about horizontal shifts for the same period.

Key words: Skopje Valley, GNSS, geodynamics.

ESTABLISHING OF GNSS NETWORK FOR 2D GEODYNAMIC DETERMINATION OF SKOPJE VALLEY

Taking into account all geotectonic and geomorphological information about the territory of the Skopje epicenter area and Skopje Valley as part of it, it is concluded that the establishment of a network of points that will determine the coordinates in different time periods and define the movements of this region depending of geodynamic events is more than necessary (Bogdanovski Z., 2008).

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In view of modern technical and technological achievements in measurement technology, global positioning system is the best choice to perform the measurements for determining the coordinates of points for geodynamic occurrences. While establishing the basis for GNSS measurements in order to determine the geodynamic shifts, it is more than necessary for the points on which the measurements will be performed to be stabilized and properly founded on stable ground (Fig. 1). The pillars of Skopje trigonometric network are appropriate and logical choice for this purpose (Bogdanovski Z., Srbinoski Z. 2009). Namely, the city trigonometric network (CTN) has other important characteristics from the aspect of utilization of it as a geodynamic base, or a base for determining geodynamic shifts. One of these important characteristics is the distribution of this network in the area of the Skopje Valley and mountain ranges around it. This provides a possibility to choose the points for establishing the base for the geodynamic monitoring.

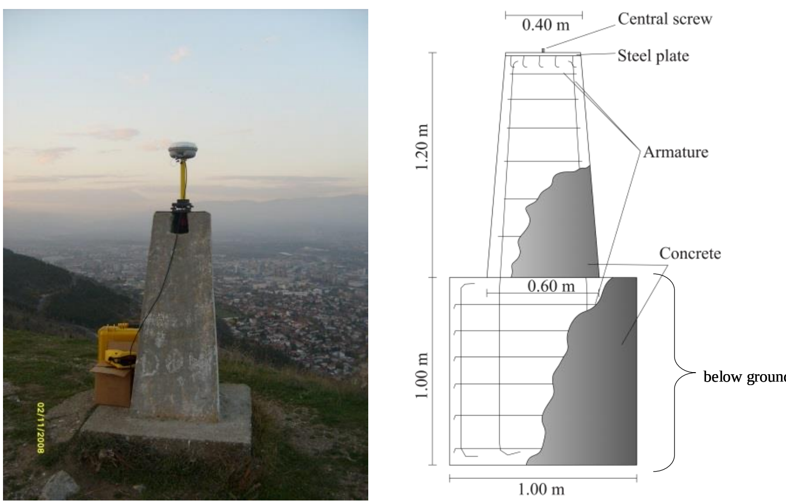

Fig 1. ***Point from Skopje trigonometric network and way of stabilization.***

The selection of points from CTN which form the base for the geodynamic determination of Skopje Valley was based on several conditions. A basic condition set in the designing of the network was the position of the points and their arrangement in relation to Skopje Valley as well as the mountains Skopska Crna Gora and Vodno. In addition, there was a condition from geometric aspect to design a rational geometric shape so that the network will satisfy the standards for the design of geodetic networks. In order to satisfy the requirement of accessibility of points, points which are easily accessible (by car) were chosen. Accordingly, the choice fell on the following six trigonometric points:

- Trigonometric point -TP 2003, located on the southern slopes of the mountain Skopska Crna Gora, nearby the village of Mirkovci. This point is the most northern point of the CTN;
- TP 2017, located on the southeastern slopes of the mountain Skopska Crna Gora, nearby the village of Bulachani;
- TP 2009 which is located in the central part of the Skopje Valley, more precisely in the settlement of Butel;
- TP 2079, located on the central part of the mountain Vodno, in the area Markovo Kale;
- TP 2059, located on the southeastern slopes of the mountain Vodno, nearby the village of Batinci, and
- Trigonometric point 2070, located on the southwestern slopes of the mountain Vodno, nearby the village of Govrlevo (Bogdanovski Z., 2013).

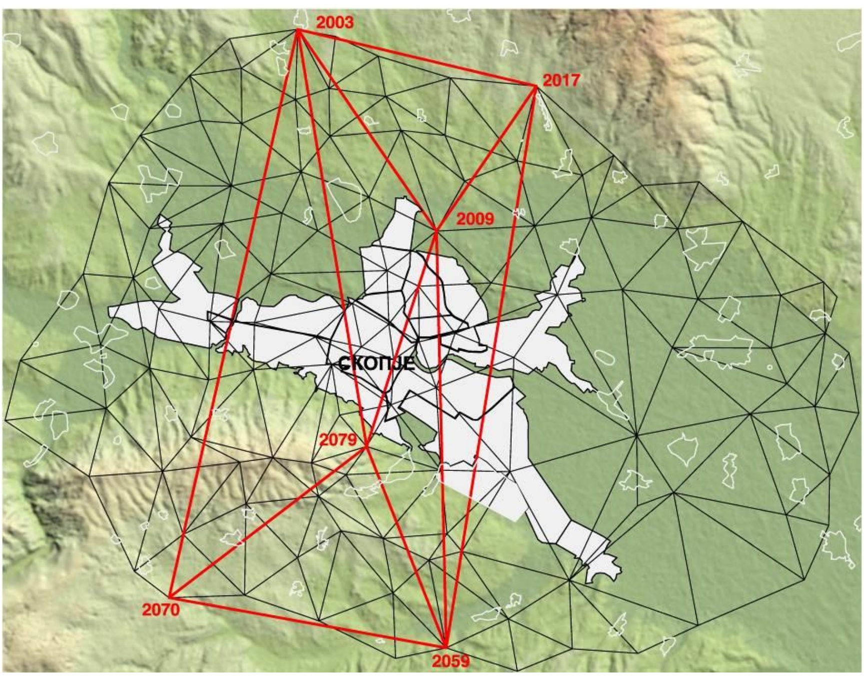

Fig 2. ***The geodynamic base in relation with CTN of Skopje.***

The main characteristics of such establish network of 6 points are:

- The points represent concrete pillars which are properly founded with shape of cut four-pyramids;
- The network formed by these points is with direction from northeast to southwest and practically connects the mountains Skopska Crna Gora and Vodno.
- The maximal distance of 20.7 km in the network is between points 2003 and 2059;
- The minimal distance of 5.7 km in the network is between points 2017 and 2009.

INSTRUMENTS AND SOFTWARE USED FOR PERFORMING AND PROCESSING GNSS MEASURMENTS FOR SERIES 2008 AND 2012

The measurements in the Global positioning system are carried out with appropriate measuring technology and adequate equipment. The instruments with which the measurements for geodynamic purposes are carried out should possess certain characteristics and meet certain standards, which will lead to the desired accuracy of the measured base vectors. Nowadays there are a lot of reputable manufacturers of instruments and equipment for global positioning.
In the measurement campaigns carried out to establish the geodynamic base for Skopje Valley 4 instruments from the renowned Swiss company Leica Geosystems and 2 receivers from a reputable U.S. company Trimble were used.
From Leica Geosystems were used – 2 *Leica GX1230* and 2 *Leica ATX1230*.
The two *Trimble R6* receivers which were used to perform the GPS measurements belong to the group of dual-frequency receivers with integrated antennas (Fig 3).

Fig 3. ***Trimble R6 receiver.***

Data processing was carried out with *Leica Geo Office Combined* (v 4.0) software and *Trimble Business Center* (v 2.0).
This software is a modern tool for processing GNSS measurements, based on Windows environment.
To get the coordinates of the points with an accuracy which is needed to define their position, it is necessary to perform the processing of measurements with known precise satellite ephemerides at the time of measuring. For that purpose the *Leica Geo Office Combined* software offers input of precise ephemerides already downloaded from the Internet. This software works with the following extensions of precise ephemerides: **.sp3;*.sp3c;*.pre*.
The subroutine *MOVE3* is an integrated part of this software; this subroutine can make network adjustment by the least squares method.
The second software, *Trimble Business Center v 2.0,* is also software that works on a *Windows* platform.
In this software there is an option for type choosing of data processing according to measurements taken with Trimble receivers or receivers from other manufacturer. This is very important because phase corrections depending on satellite azimuth and satellite elevation relative of GPS antenna type are not a default option in the basic style of calculation in this software.
Adjustment of the network of GPS points should be performed after the processing of data and getting the needed base lines. The adjustment of the network should be in accordance with the standards for adjustment of networks for monitoring of geodynamic processes (Srbinoski Z. at al. 2013).

RESULTS OF GNSS MEASURMENTS PERFOMED IN TIME SERIES 2008 AND 2012

The analysis of geodynamic phenomena can be performed from different aspects and it represents multidisciplinary area of research. In this part of the research, the task of geodesy comes down to determining the horizontal and vertical movements of the Earth’s crust, within geodynamic bases that cover a certain territory. For the determination of Earth's crust movements it is necessary to perform several series of measurements, and then to compare their results.
The results of the GNSS measurements on the geodynamic base of the Skopje Valley are analyzed in this paper. The comparison of two or more series of GNSS measurements can result in conclusions about the horizontal movements of the Earth's crust, while for the determination of vertical

deformations, it is necessary to perform extensive leveling measurements or combination of GNSS measurements and InSAR measurements.
Two series of measurements that were performed on this basis are with next characteristics:

- The first series was performed in October 2008,
- The second series was performed in September 2012.

Both series of measurements were performed according to standard parameters that are used for geodynamic needs:

- The measurements are performed using dual-frequency GNSS receivers;
- Minimum length of observation session on each of the measuring points was 8 hours;
- The registration of GNSS data was with observable logging rate of 15”;
- In the process of calculation were used precise ephemerides.

The two series of measurements are processed using Leica Geo Office Combined, and controls of those calculations were made with software Trimble Business Center.
From the results of the adjustment of base lines and calculation of points coordinates from the geodynamic base in the first and second series it can be concluded that the points from the geodynamic network are determined with high positional precision ranging between ± 1-2 mm.
The Cartesian coordinates of the points and their positional accuracy in the first series are shown in Table 1. The Cartesian coordinates of the points from the second series of measurements and their positional accuracy are shown in Table 2.

Table 1. ***Cartesian coordinates of points in first series (2008)***

Point	***Coordinates (WGS 84)***			***Accuracy***	
	X	***Y***	***Z***	m_p	m_D
2003 Mirkovci	4413633.8708	1730176.2492	4253435.9154	0.0012	0.0022
2009 Butel	4415994.0400	1735923.9510	4248434.4742	0.0011	0.0020
2017 Bulachani	4412038.3425	1737888.5576	4252091.9738	0.0010	0.0019
2059 Batinci	4424433.4789	1739503.3525	4238416.9017	0.0011	0.0020
2070 Govrlevo	4426812.5409	1730750.6561	4239793.4217	0.0012	0.0022
2079 Markovo K.	4421374.3783	1735554.9321	4243399.5917	0.0008	0.0015

Table 2. ***Cartesian coordinates of points in second series (2012)***

Point	***Coordinates (WGS 84)***			***Accuracy***	
	X	***Y***	***Z***	m_p	m_D
2003 Mirkovci	4413631.8634	1730175.9734	4253434.8726	0.0020	0.0038
2009 Butel	4415992.0008	1735923.6636	4248433.3820	0.0018	0.0035
2017 Bulachani	4412036.3520	1737888.2920	4252090.9418	0.0018	0.0035
2059 Batinci	4424431.4916	1739503.0819	4238415.8632	0.0020	0.0039
2070 Govrlevo	4426810.5567	1730750.3876	4239792.3850	0.0019	0.0038
2079 Markovo K.	4421372.3615	1735554.6535	4243398.5235	0.0014	0.0027

Because of the nature of the GNSS measurements, the results of free networks adjustment (as is our case) are not directly comparable. Therefore it is necessary to transform the measurements from the two series in the same geodetic datum. One of the ways for such transformation, which is used in the area of geodynamics, is the adoption of common coordinates for a point of the network in both systems (series). In our case, the point 2070_Govrlevo was used. For this point the coordinates from the first series are used and all other points of the second series are moved in relation to it.
As we already mentioned earlier, there are many ways of analyzing the measured values, and an analysis of surface deformation obtained and based on two series of measurements will be carried out in this paper. This analysis is based on the comparison of adjusted base vectors, and for this aim it is necessary for the ellipsoidal coordinates of points to be transformed into grid coordinates in one of the known cartographic projections.
To increase the accuracy of the calculation, a special cartographic projection was made, based on the characteristics of the state cartographic projection (Srbinoski Z., 2009). It is a transverse cylindrical conformal cartographic projection with central meridian defined with geodetic longitude on geographic center of geodynamic network:

$$L = 21^{o}\ 25'\ 36''$$

In this way, the deformations of cartographic projection are within the accuracy of measurement and do not affect the results of the measurements and their application in the analysis of geodynamic shifts.
The grid coordinates from the points of the geodynamic base in the first series are shown in Table 3, while the grid coordinates of the points in the second series are shown in Table 4.

Table 3. ***Grid coordinates from first series (2008)***

Points	***Coordinates***	
	Y	***X***
2003 Mirkovci	498251.8742	4661711.1838
2009 Butel	502739.8363	4655119.9332
2017 Bulachani	506013.2963	4659821.1125
2059 Batinci	502988.7711	4641544.6331
2070 Govrlevo	493972.7656	4643225.3418
2079 Markovo K.	500430.9441	4648117.7000

Table 4. ***Grid coordinates from first series (2012)***

Points	***Coordinates***	
	Y	***X***
2003 Mirkovci	498251.8758	4661711.1955
2009 Butel	502739.8387	4655119.9308
2017 Bulachani	506013.3012	4659821.1192
2059 Batinci	502988.7702	4641544.6343
2070 Govrlevo	493972.7656	4643225.3418
2079 Markovo K.	500430.9465	4648117.6993

The final values of the base vectors in the two series are calculated based on the grid coordinates of the points and then these vectors are compared. (Gospodinov S., 2011). The results of the analysis are shown in Table 5 and Figure 4.

Similar results, but with lower intensity are registered at point 2017_Bulachani. The deformations of base vectors to this point are with intensity from 6.4 mm to 8.9 mm; it also indicates significant displacement of this point.

The movements of the points 2003 and 2017 indicate possible active fault that passes between them and the other points, as well as the fault between points 2003 and 2017, which confirms the data from the Neotectonic map (Bogdanovski Z., 2013).

Table 4. **Comparisons between base vectors in two series**

Base vector	Values		differences (mm)
	2008	2012	2012-2008
2070 - 2003	18974.6443	18974.6560	*11.7*
2070 - 2079	8102.0515	8102.0530	*1.5*
2070 - 2059	9171.3214	9171.3203	*-1.1*
2059 - 2079	7053.2041	7053.2011	*-3.0*
2059 - 2017	18525.0493	18525.0557	*6.4*
2079 - 2003	13767.0312	13767.0435	*12.3*
2079 - 2009	7373.0762	7373.0746	*-1.6*
2079 - 2017	12966.5925	12966.6002	*7.7*
2009 - 2003	7974.1074	7974.1195	*12.1*
2009 - 2017	5728.5799	5728.5888	*8.9*
2003 - 2017	7988.2440	7988.2484	*4.4*

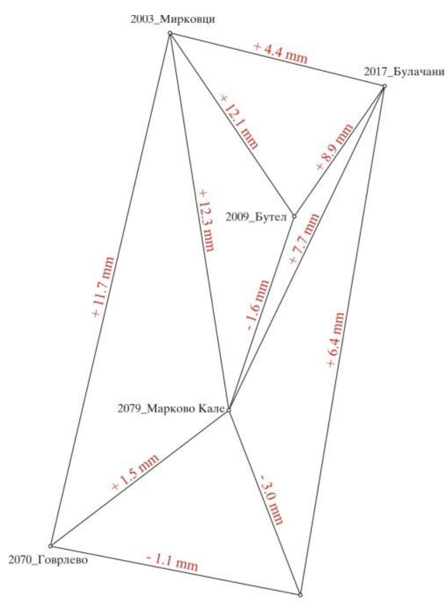

Fig 4. **Comparison of base vectors from two series.**

On the other hand, there are no significant differences at the other base vectors, which lead us to note that there is no displacement of other points from the geodynamic base. Namely, the results in the table indicate that the deformations are within the accuracy of measurement, from which we can reach the conclusion that the points in the central and southern part of the network are relatively stable.
In further research, these data can be a basis for many analyzes, including basics of tensors mathematics. These analyzes can result in the definition of angled and surface deformations for the geometric centers of the figures, their trends and movements, and some other data which are interesting for geodynamical research.

CONCLUSIONS

The determination of the local geodynamic phenomena in Skopje Valley was performed on the basis of GNSS measurements within the framework of a specially designed geodynamic network (base) for that aim. The geodynamic base consists of 6 points from the trigonometric city network of Skopje, which are carefully selected in consultation with geologists and seismologists.
In this paper, processed data from two series of 8-hour measurements in the network performed in 2008 and 2012 are used to define the local movements of the Earth's crust. The processing of data was performed with the *Leica Geo Office Combined* and *Trimble Business Center* software. From the data in this paper it can be concluded that the points in the geodynamic network are determined with high positional precision which is around ± 1 mm.
For the purpose of data analysis, calculation is made with grid coordinates of the points in a special cartographic projection. This projection is a transverse cylindrical conformal cartographic projection with central meridian defined with geodetic longitude on the geographic center of the geodynamic network. In that way, the deformations on the cartographic projection become insignificant, and the accuracy of the processed base vectors is maximal.
The analysis of the results of calculations is performed by *comparing the base vectors* between the measurement points. The analyses indicate that the maximum difference of base vectors appears to point 2003_Mirkovci and are in range between 11.7 mm and 12.3 mm, and suggests that this point is significantly moved. The same results but with smaller intensity are present at point 2017_Bulachani. The deformations of base vectors to this point are with intensity from 6.4 mm to 8.9 mm; it also indicates significant displacement of this point.

On the other hand, there are no significant differences at the other base vectors, which lead us to note that there is no displacement of other points from the geodynamic base. Namely, the results in the table indicate that the deformations are within the accuracy of measurement, from which we can reach the conclusion that the points on the central and southern part of the network are relatively stable. The above mentioned analyzes of the geodynamics of the Skopje Valley result in the following general conclusions:

- The time difference of about 4 years between these two series of GNSS measurements provides an opportunity to get quality and significant results for the deformations of the Earth's crust in the area of Skopje Valley.
- In order to determine possible trends in the Earth's crust deformations, it is more than necessary to perform more series of GNSS measurements, whose results would be compared with the results of the zero series.

For more comprehensive analysis of geodynamic phenomena in the region of Skopje Valley it is more than necessary to expand the geodynamic network with more pillars from the city microtrigonometric network of Skopje.

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