CORRELATION BETWEEN GEODETIC AND GEOLOGICAL MODELS IN THE GEODYNAMIC NETWORK OF THE CITY OF ZAGREB

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ABSTRACT

Since 1997 till 2008, several series of precise GPS measurements have been conducted on specially stabilized points of Geodynamical Network of City of Zagreb with purpose of investigation of tectonic movements and related seismic activity of the wider area of the City of Zagreb. From this series of GPS measurements geodetic model of tectonic movements has been created. In the area of interest, independent geological investigations have been conducted through even longer period of time which resulted in geological model of tectonic movements. Comparison and correlation of these two independent models will be presented in this paper.

INTRODUCTION

Through the realization of the project Basic GPS-Network of the City of Zagreb in 1997, Croatian capital got a modern, geodetic foundation of high accuracy. Network was planned as the basis for investigations of tectonic movements and related seismic activity of the wider area of the City of Zagreb. Basic part of the network consists of 43 specially stabilized geodetic points to meet the specific criteria for geodynamic points. After the second series of GPS measurements in year 2001, the network has become "Geodynamic Network of the City of Zagreb" (Medak & Pribičević 2001), (Medak & Pribičević 2003). The City of Zagreb has recognized the importance of this project and GPS campaigns have been performed in years 2004, 2006, 2007 and in 2008 (Pribičević et al 2004), (Medak et al 2007a).

After six series of GPS-measurements in period from 1997 to 2008, the analysis of the results with scientific software GAMIT/GLOBK show significant movement on GPS points as a result of geodynamic activity in the research area. From the analysis results the geodetic model of tectonic movements has been created and scientific comparison with geologic model created on the basis of age-long research. The correlation coefficient between geodetic and geologic model has been calculated and shows high degree of correlation thus giving credibility to both methods of research. Systematic analysis has been conducted over geodetic and geologic results giving as a result unique interdisciplinary model of crust movements over wider Zagreb area.

GEODYNAMIC NETWORK OF THE CITY OF ZAGREB

Geodynamic network of the City of Zagreb is a special local network around the Croatian capital which was observed by GPS in six campaigns in period between 1997 and 2008.

The Geodynamic network consists of more than 40 specially stabilized points on wider area of the City of Zagreb and covers area of about 700km^2 (Medak & Pribičević 2002). Since the network was going to be used for monitoring of tectonic movements by GPS methods special attention was given to the design of the network and to the stabilization of monuments (Solarić, M. 1999), (Schmitt, 1985). As shown on the figure 1, most of the monuments have pilots that go up to 14 meters deep to consolidated ground. On the top of every monument is a steel mark with winding for the special extension thus insuring stability of points through long periods of time and precise GPS antenna reoccupation

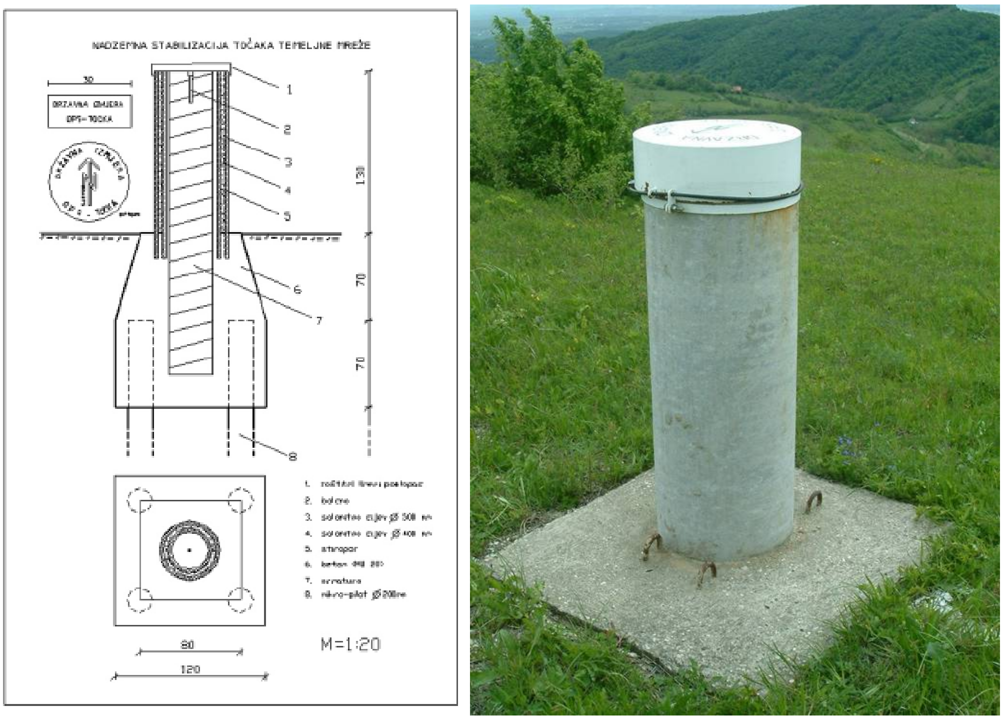


Figure 1: Specially stabilized monument on Geodynamic network of the City of Zagreb.

GPS OBSERVATIONS

Since 1997 GPS measurements on the Geodynamic network of the City of Zagreb were conducted through GPS measurement campaigns every few years. Each campaign consists of two to tree 24 hour sessions. First two campaigns in 1997 and 2001 had tree 24 hour sessions with 15 second observation interval thus giving 5670 epochs. All later campaigns had 24 hour sessions but with 30 second interval giving 2880 epochs (Medak et al 2007a).

All conducted campaigns had only Trimble GPS receivers and antennas. There were 8 conducted GPS campaigns: 1997, 2001, 2003, 2004, 2005, 2006, 2007 and 2008. Only five of those were observation of complete Geodynamic network: 1997, 2001, 2004, 2006, and 2008 (41 points). Two campaigns were conducted for observing densification points 2005 and 2007 (11 and 21 points) (Medak et al 2007b).

Table 1 shows all conducted campaigns including number of points and used instruments

Table 1: GPS campaigns on Geodynamic network of the City of Zagreb

Campaign	Date	sessions	points	receivers
Zagreb 1997	27.-29.10.1997.	2	43	27
Zagreb 2001	25.-28.06.2001.	3	40	16
Zagreb 2003	22.-23.06.2003.	1	13	13
Zagreb 2004	17.-20.06.2004.	3	39	13
Zagreb 2005	10.-11.09.2005.	1	11	11
Zagreb 2006	22.-25.06.2006.	3	41	13
Zagreb 2007	13.-15.07.2007.	2	21	13
Zagreb 2008	10.-13.06.2008.	3	41	13

PROCESSING AND RESULTS

Similar processing techniques were applied to all sets of results. Scientific GPS-software GAMIT was used to process and compare all epochs (1997 till 2008) and the GLOBK module was used for origin analysis and calculation of displacements (Dong et al 1998), (Herring et al, 2006a), (Herring et al, 2006b).

Data was processed in series: 1997-2001, 2001-2004, 2004-2006, 2006-2007, and 2007-2008. Also a cumulative solution was calculated including all series of measurements form 1997 to 2008.

The highest velocity rates were calculated for period 2006-2007 which shoved to be most geodynamically active. Figure 2 shows velocity rates for that specific period and Table 2 shows statistical representation of absolute values of velocity rates 2006–2007. mm/yr.

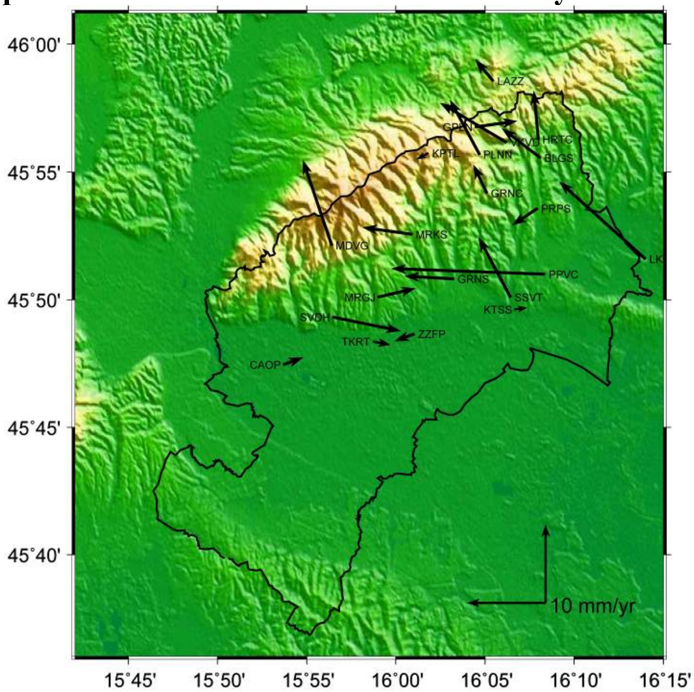


Figure 2: Velocity rates for period 2006-2007.

Table 2: Statistical representation of absolute values of velocity rates 2006–2007. mm/yr.

	v *mm/yr*	*v* *mm/yr*	v_{hz} *mm/yr*	v_H *mm/yr*
min.	**0,2**	**0,57**	**1,43**	**0,60**
max.	**10,70**	**19,36**	**19,37**	**50,27**
avg.	**3,14**	**4,86**	**6,43**	**16,25**

Velocity rates calculated for the complete period form 1997 to 2008 are much smaller due to different active zones of the Zagreb area from year to year giving thus sometimes opposite velocity directions for the same points. Velocity rates for the period 1997 to 2008 are shown in Figure 3 and Table 3 shows statistical representation of absolute values of velocity rates 1997–2008. mm/yr.

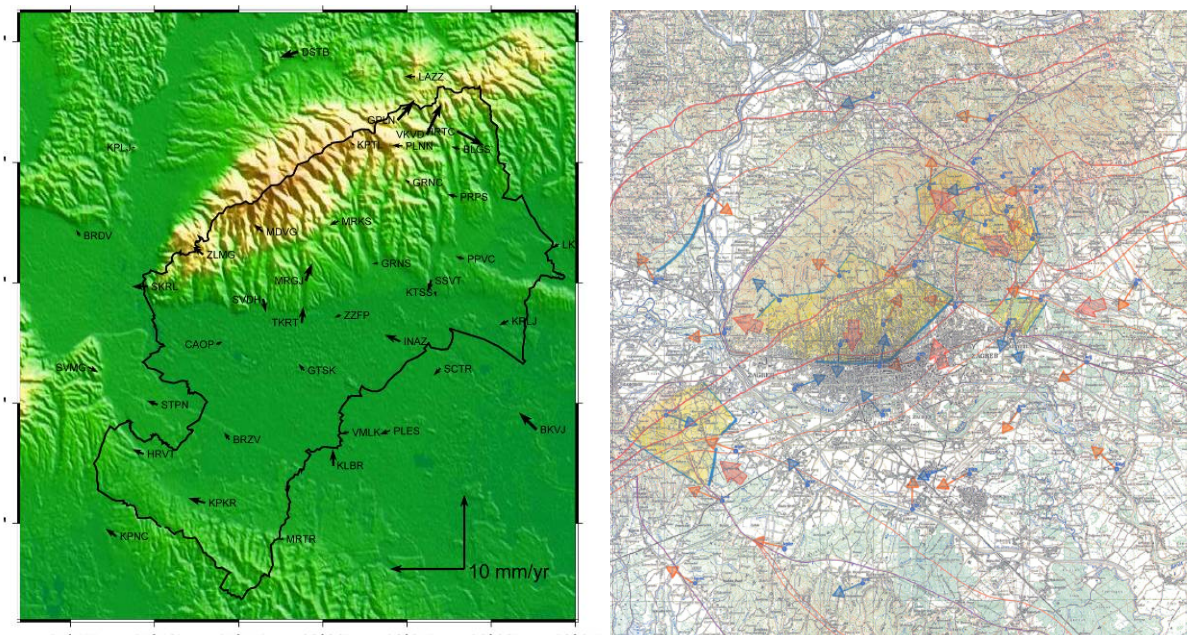


Figure 3: Velocity rates for period 1997-2008.

Table 3: statistical representation of absolute values of velocity rates 1997–2008. mm/yr.

	v *mm/yr*	*v* *mm/yr*	*Vhz* *mm/yr*	*vH* *mm/yr*
min.	**0,03**	**0,04**	**0,12**	**0,02**
max.	**3,93**	**3,42**	**4,34**	**17,48**
avg.	**0,83**	**1,03**	**1,45**	**1,97**

Geodetic velocity model was created using IDW (Inverse Distance Weighting) interpolation and taking into account fault model on wider Zagreb area. The result is shown on Figure 4.

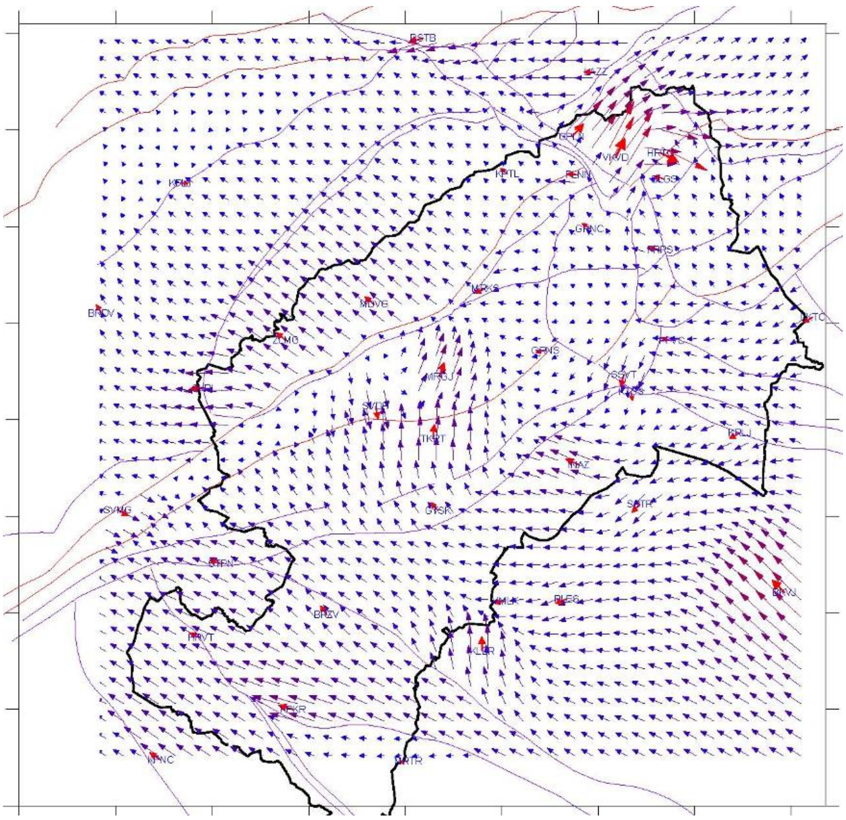


Figure 4: Geodetic velocity model created using IDW interpolation with respect to faults model.

CORRELATION OF GEODETIC AND GEOLOGIC MODEL

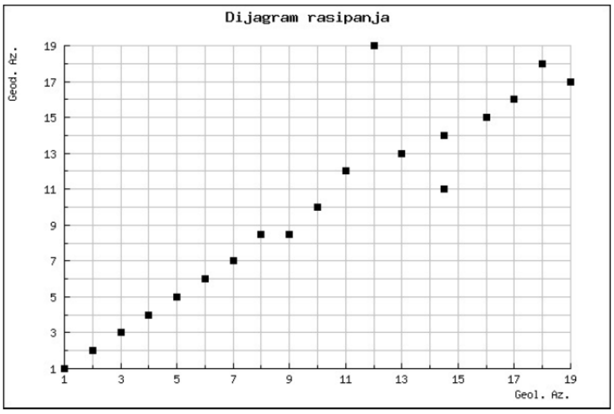
As already described earlier, from the analysis results, the geodetic model of tectonic movements has been created and scientific comparison with geologic model which was created on the basis of age-long research (Medak et al 2002). Calculation of correlation coefficient between geodetic and geologic model will give the measure of correlation and confirmation of both methods.

Azimuths of directions of movements of main structure blocks have been taken as a measure. 19 data pairs (azimuths) were used for calculation and since each azimuth is a single variable rated with two independent methods, correlation coefficient is calculated by Spearman formula for rank correlation (Šošić, 2004).

$$r_s = 1 - 6 \sum_{i=1}^{n} \frac{{d_i}^2}{n(n^2 - 1)} \tag{1}$$

Table 4: Correlation coefficient by Spearman formula

red.br.	x_i	y_i	$r(x_i)$	$r(y_i)$	d_i	d_i^2
1	297	299	14	14.5	-0.5	0.25
2	277	281	13	13	-1	1
3	255	262	10	10	0	0
4	260	299	11	14.5	-3.5	12.25
5	191	187	6	6	0	0
6	141	160	4	4	0	0
7	220	204	8.5	8	0.5	0.25
8	220	224	8.5	9	-0.5	0.25
9	18	18	2	2	0	0
10	346	344	17	19	-2	4
11	345	333	16	17	-1	1
12	324	319	15	16	-1	1
13	383	279	19	12	7	49
14	274	271	12	11	1	1
15	189	164	5	5	0	0
16	140	146	3	3	0	0
17	212	197	7	7	0	0
18	351	338	18	18	0	0
19	8	10	1	1	0	0
	-	-	190	190	-1	69



Calculating of correlation coefficient by above given formula (1) for Spearman rank correlation we get r_s=0.93 with 1% significance level (or 99% in gaussian model).
The correlation coefficient between geodetic and geologic model shows high degree of correlation thus giving credibility to both methods of research.

Figure 5 shows unique interdisciplinary model of crust movements over wider Zagreb area as a result of systematic analysis over geodetic and geologic results.

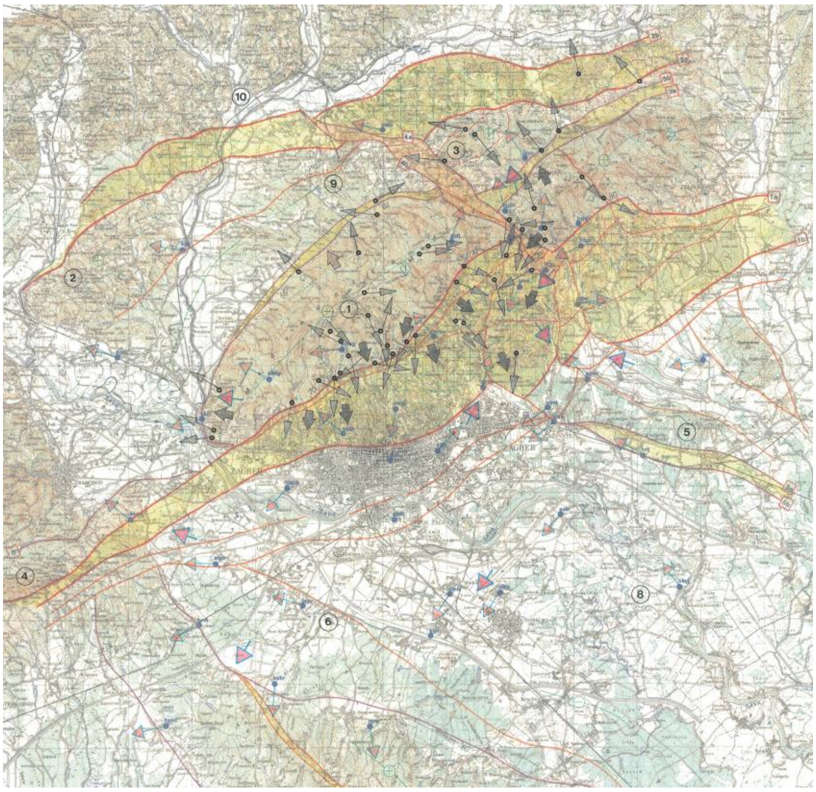


Figure 5: Interdisciplinary model of crust movements over wider Zagreb area.

CONCLUSION

The latest results enable geoscientists to compare geologic results with geodetic-kinematic movements that are less scarcely interpolated than before.
Maximal absolute value of velocities for the cumulative solution in horizontal direction are 4.3mm/yr, and in vertical 17.5 mm/yr. Largest absolute values have been calculated for the period 2006 - 2007 and are 19.4 mm/yr in horizontal and 50.3 mm/yr in vertical direction, which represents significant tectonic movements, but we have to point out that average velocities are around 3mm/yr.
High correlation coefficient gives credibility to both geodetic and geologic investigations of tectonic movements on research area and allows easier combination and creation of unique interdisciplinary model of tectonic movements.
It is expected that this research will give us the new insight in processes that might trigger hazardous landslides or even earthquakes.

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