The European Reference System in Bulgaria

G. MILEV[1], M. MINCHEV[2], G. VALEV[3], K.VASSILEVA[1], P. GABENSKI[4], M. MATOVA[5]

Abstract

The article outlines in brief the necessity, prerequisites, requirements and meaning of EUREF for Bulgaria, and summarizes the design, set up, observation, processing and endorsement of the relevant GPS network. The later and the European Vertical Reference Network (EUVN) as its successor are closely related to the regional and local geology and seismotectonics and recent research activities in that field. Presented are various applications of EUREF in Bulgaria ranging from definition of a new national reference system to surveying, mapping and cadastral works, geodynamic investigations, as well as enlargement of the EUREF network in neighbouring countries. A monograph dedicated to these problems is under preparation.

1. Introduction

Proper grounds for introducing the European Reference System in Bulgaria were set up in 1996, when the efforts of a joint team of researchers and field surveyors of the Bulgarian Academy of Sciences (the former Laboratory of Geotechnics, now Central Laboratory of Geodesy) and soldiers of the Military Topographic Service, supported by and in close co-operation with the former German Institute of Applied Geodesy (IfAG), now Federal Mapping and Surveying Agency (BKG), finally led to endorsement of results of the EUREF-Bulgaria GPS campaigns held in 1992 and 1993. With this, after decades of absence, Bulgaria got back to its inherent place in geodesy in Europe and on the global scale, which is of key importance for various practical activities, international co-operation and harmonization with the EC standards.

Over the past ten years a huge amount of work has been done within the framework of projects as EUREF, EUVN, UNIGRACE and others aimed at fundamental research and specific practical applications. The outcome of these activities is collected in a monograph, entitled as this paper, and drafted presently in Bulgarian. Following the monograph structure, below are outlined the most important steps of the Bulgarian EUREF activities.

2. Introducing EUREF and EUVN into Bulgaria

2.1 The EUREF network in Bulgaria

2.1.1 Network design

To integrate Bulgaria with EUREF, it was necessary to choose some representative points which to be fixed reliably on the ground and prepared for further use as GPS stations during the observation campaigns. Such points must meet various requirements, first of all the EUREF site location specifications. On the one hand, the available geological and seismotectonical information must also be taken into account, as well as the existing trigonometric control points and levelling benchmarks. Thus, a network of seven basic and one back-up points was designed initially, which was extended later on to 15 points, called the BULREF network (Fig. 1) [3, 7]. As required, a site catalogue was compiled providing sketches, map fragments and attribute data.

[1] Georgi Milev, Keranka Vassileva: Bulgarian Academy of Sciences, Central Laboratory of Geodesy, Union of Surveyors and Land Managers, 108 Rakovski St., P.O.Box 431, BG - Sofia 1000, Bulgaria; Fax: +359 - 2 - 724 638 / 987 93 60, Tel.: +359 - 2 - 70 04 06 / 713 24 07 / 728 471, E-mail: milev@bgearn.acad.bg

[2] Momchil Minchev: Bulgarian Geoinformation Company, Bulgarian Geoinformation Company, P.O.B. 132, BG - 1618 Sofia, Bulgaria; Fax: +359 - 2 - 9559 - 372, Tel. +359 - 2 - 9559-543, Mobile: +359 - 88 - 220 391, E-mail: minchev@mail.otel.net

[3] Georgi Valev: University of Architecture, Civil Engineering and Geodesy, Christo Smirnensky 1, BG - 1421 Sofia, Bulgaria; Fax: +359 - 2 - 65 68 63, Tel.: +359 - 2 - 77 87 88, E-mail: valev@techno-link.com

[4] Plamen Gabenski: Ministry of Defence, Military Topographic Service, Levski Str. 3, BG - 1000 Sofia, Bulgaria;

[5] Margarita Matova: Bulgarian Academy of Sciences, Geological Institute, BG - 1000 Sofia, Bulgaria;

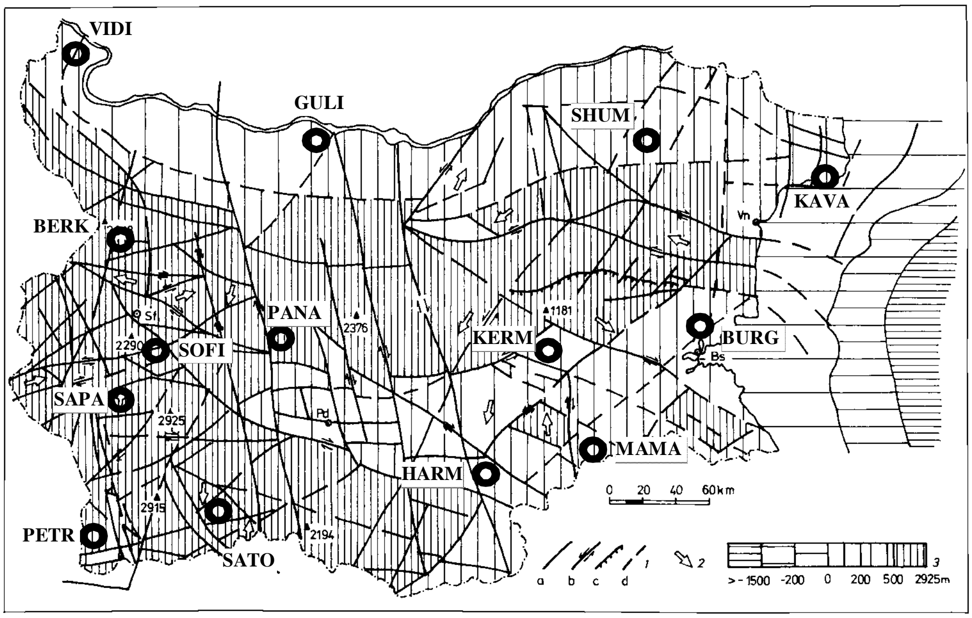

Fig. 1: The BULREF network sites shown on a map of recent earth crust fragmentation and vertical differentiation. 1. Fault lines: a) normal fault, b) strike-slip, c) thrust, d) suspected; 2. Directions of horizontal block movements; 3. Blocks of specific vertical displacement and recent level: a) below 1500 m, b) 1500 – 501 m depth, c) 500 – 0 m depth, d) 0 – 199 m height, e) 200 – 499 m height, f) 500 – 2925 m height.

2.1.2. GPS campaigns

Upon signing co-operation protocols between the above mentioned Bulgarian and German institutions, in 1992 and 1993 were carried out international GPS campaigns, known as EUREF-BG-92 and 93 [5]. The first one included 7 Bulgarian points, whilst the second campaign spread over the whole set of 15 BULREF stations, with the purpose to establish control over the main earth crust faults with proven or supposed recent tectonic activity, and connect the network to the WEGENER-MEDLAS Geodynamic Project. To provide a junction to the existing EUREF network, in the 1992 campaign were included two SLR/EUREF-89 sites in Greece, one SLR site in Turkey and two EUREF-East'91 sites in Hungary. In both campaigns were available observations collected at the four closest permanent IGS stations, Graz, Matera, Wettzell, Zimmerwald, which provided more accurate reference data than the neighbouring junction points.

After the EUREF campaigns were performed GPS measurements at the Krupnik (1992) and Chirpan (1993) local geodynamic networks. The first one included 13 point covering the crossing area of the Struma and Krupnik faults, whilst the Chirpan network consisted of 15 points located in the corresponding seismic zone. Both networks were connected to EUREF by three closest Bulgarian EUREF points.

All 15 EUREF-BG-92 and 93 stations in Bulgaria are tied to first-order control network using GPS and precise levelling, thus providing data for various analyses and computation of transformation parameters between existing datums and EUREF.

2.1.3. Processing and endorsement of results

The EUREF-BG-93 observation data were collected using Trimble 4000 SSE P-code cross-correlating receivers, instead of the old-fashioned SST units implemented in 1992 which square the signals in the L2 band. Besides, the satellite status in 1993 was rather favourable and allowed for continuous 24 hour observations whilst the previous campaign was composed of 8 hour daily sessions. However, the 1992 data set includes observations gathered at neighbouring junction stations providing additional connection to EUREF reference frame. Therefore, a processing strategy to combine both campaigns was chosen and realized by means of the Bernese software, version 3.5 [1, 2].

Following the resolutions of the EUREF symposium held in Helsinki, 1995, the campaign solutions were constrained to the EUREF reference frame using the four IGS stations mentioned above. The final results were submitted to the Technical Working Group and endorsed at the Ankara'95 symposium as of Class B, with 1 cm accuracy at the epoch of observation (Table 1) [2].

In fact this assessment is valid for all points observed in 1992 and 1993, though only 7 of them (BURG, GABR, HARM, KAVA, PETR, SOFI, VIDI) are formally adopted as EUREF points. The entire set of 15 points (i.e. the BULREF network) forms a precise spatial reference network which serves various scientific and practical purposes within the country.

2.1.4. EUREF campaigns in Romania, Macedonian and Albania

Four Bulgarian EUREF points provided a junction for the EUREF-Romania campaign held in 1994. Joint Bulgarian and German observation teams performed five 24 hour observation sessions at the GABR, KAVA, SOFI and VIDI stations [5]. The SOFI station took also part in EUREF-Macedonia (1996) and EUREF-Albania (1997) campaigns [5].

Table 1. EUREF-BG-92/93 Final results

Site EUREF No		ETRF-89 Cartesian coordinates	r.m.s. [mm]		WGS84 Latitude, Longitude and Height	r.m.s. [mm]
Petrich	X	4 402 939.092	757	•	41° 27’ 31.65554"	2410
	Y	1 880 254.886		•	23° 07’ 28.85602"	
0551	Z	4 201 276.154		h	804.471	
Harmanli	X	4 280 050.108	757	•	41° 53’ 03.98202"	249
	Y	2 073 328.270		•	25° 50’ 46.78212"	
0552	Z	4 236 244.769		h	281.994	
Gabrovo	X	4 227 590.012	657	•	42° 57’ 46.47243"	2
	Y	1 996 278.274		•	25° 16’ 36.46183"	4
0553	Z	4 324 909.571		h	619.615	9
Vidin	X	4 233 068.613	757	•	44° 04’ 38.14258"	2410
	Y	1 773 729.946		•	22° 44’ 04.33790"	
0554	Z	4 414 410.419		h	211.961	
Kavarna	X	4 083 131.581	757	•	43° 24’ 48.51855"	2410
	Y	2 205 288.816		•	28° 22’ 24.12309"	
0555	Z	4 361 084.208		h	145.970	
Sofia	X	4 319 372.394	757	•	42° 33’ 21.93298"	249
	Y	1 868 687.567		•	23° 23’ 41.02366"	
0556	Z	4 292 063.797		h	1119.583	
Burgas	X	4 168 849.879	757	•	42° 39’ 58.79598"	2410
	Y	2 164 800.907		•	27° 26’ 31.03981"	
0557	Z	4 300 556.451		h	350.026	

2.2. Mobile laser and permanent GPS stations

As agreed by the Bulgarian and German parties, a SLR station and a permanent GPS station were established at the Sofia EUREF site.

2.2.1. Mobile laser station

The purpose of the mobile SLR station is to strengthen the WEGENER-MEDLAS geodynamic network and to provide additional information based on advanced positioning methods, other than GPS. Therefore, a special concrete pad was built up and furnished with a set of reference markers precisely positioned with regard to the EUREF point located nearby. A team of the Wettzell Observatory equipped with a MTLRS-1 mobile satellite ranging system completed laser observations in October 1995 [5]. The data was processed in Potsdam, Germany and yielded results as given at Tab.2.

Table 2: SLR coordinates of Sofia station

Station No	X [m]	Y[m]	Z[m]
SOFI 7505	4 319 400.163	1 868 699.058	4 292 023.691
r.m.s.	0.015	0.019	0.013

2.2.2. Sofia permanent GPS station

Operational since 20 May 1997, the Sofia permanent GPS station is equipped with a Rogue SNR 8000 receiver, connected to a Dorne-Margolin antenna installed directly on the Sofia EUREF point (SOFI pillar) [5]. The observations are regularly downloaded and sent via Internet to the Wettzell Observatory for preprocessing and dispatching to the relevant EUREF and IGS data and processing centres. The data sample below (Fig. 2) shows the weekly solution scatter and trend in northing, easting and height as obtained in the initial period of station operation.

2.3. The Bulgarian part in the European Vertical Reference Network

A step towards European heighting system unification, which extends the EUREF activities also to the vertical component, the EUVN’97 GPS campaign included more than 200 observation points, three of them located in Bulgaria. Besides Sofia permanent GPS station, two tide-gauge points, Varna and Burgas at the Black Sea coast, were taking part in the campaign.

According to the EUVN’97 site specifications, the Varna and Burgas points were reliably monumented with concrete pillars and enforced centering devices on top of them.

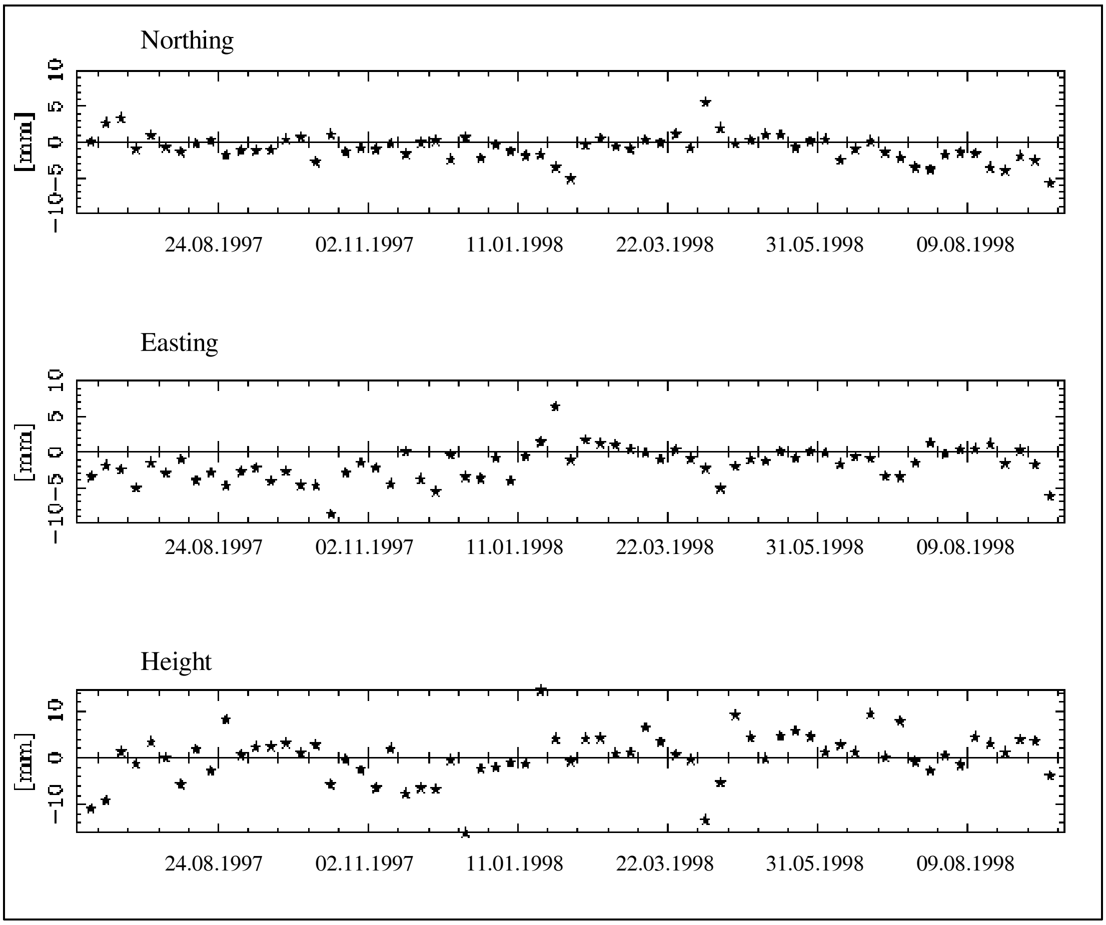

Figure. 2. Sofia permanent GPS station weekly solutions

All three Bulgarian stations were precisely connected to the National Fundamental Levelling and Gravity networks.

The observations collected in May 21-29, 1997, were processed at BKG and the Astronomical Institute in Berne using the Bernese software, version 4.0. For that purpose two Bulgarian specialists were working with the BKG team at Leipzig. The final results concerning the Bulgarian participation in the EUVN'97 campaign are shown at Table 2 [5].

Table 2. EUVN'97 final results: Bulgarian stations

Station EUVN'97 No DOMES No	ITRF-96, epoch 1997.4 Cartesian coordinates	WGS84 Latitude, Longitude and Height
Burgas BG01	X 417 9321.474 Y 217 3955.760 Z 428 5392.059	φ 42°29'00.6286" λ 27°28'55.4800" h 41.735
Sofia BG03 11101M002	X 431 9372.239 Y 186 8687.653 Z 429 2063.867	φ 42°33'21.9370" λ 23°23'41.0298" h 1119.551
Varna BG04	X 411 5657.708 Y 217 9981.707 Z 434 3159.466	φ 43°11'33.6910" λ 27°54'33.3914" h 38.237

3. EUREF applications in Bulgaria

Amongst the variety of EUREF applications, below are outlined those which play a key role in the future development of geodesy, surveying, mapping and related matters in the country.

3.1. Improving the National GPS network concept

The datum, spatial orientation and metrics defined by ITRS and disseminated by the IERS products are realized over Europe by the EUREF network. To take practical advantage from it, the National Geodetic Network is to be improved using GPS technology as follows [6].

A primary network of some 100-110 points separated by 35 km in average shall densify the BULREF network down to a level of even point distribution without significant precision losses. To achieve it, two 24 hour observation sessions shall be performed on each network tile using dual-frequency P-code receivers. The number of tiles into which the entire network shall be split depends on the available equipment. Ten to twenty GPS sets is a reasonable number to achieve acceptable compromise between network partitioning and organization flexibility.

A secondary network of 320-330 points separated by average distances of some 20 km shall be establishing with the purpose of setting up a reference for various practical applications. The baselines shall result from observation sessions of 6 to 12 hours accomplished with dual frequency receivers which may vary in number and performance depending on the available resources.

In intensive economic regions, and wherever necessary, the GPS network can be enhanced still further, providing control points as dense as the low-cost single frequency equipment could be efficiently used. For that reason the inter-station gaps in the primary and secondary networks shall be populated with additional points determined with dual-frequency receivers, in 1-2 hour sessions.

Improved in this way, the National Geodetic Network shall include existing triangulation and nodal levelling points, Sofia and any future permanent GPS station, as well as new points, all of them reliably monumented, easily accessible in all weather conditions, and efficiently applicable both for traditional surveying and GPS methods.

3.2. System 2000

A traditional one, the Bulgarian national reference system has remained unchanged some half a century and does not provide a reliable geodetic reference in many cases, especially when advanced surveying technologies are used. The modern national reference system which the country urgently needs shall be based on the GRS80 fundamental parameters and includes the following components [8]:

1. The National Geodetic Network as defined above realizes the spatial and gravity reference frame. Each geodetic point shall become a multipurpose station providing positional and velocity information, physical and geometry data, including gravity and magnetic vector, etc.
2. A reference ellipsoid and gravity formula as defined by GRS80, and future IUGG/IAG recommendations.
3. Advanced gravity and geoidal models, such as EGM96 and EEG97, have displayed low accuracy (1 m and worse) over the territory of the country due to the incomplete data sets used in the computations. The only way to improve it is to join the work of the relevant IAG subcommission and contribute for providing sets of representative gravity and terrain data for future analyses and product generation.
4. Transformation parameter sets which provide connection to other geodetic systems. The practice of using position dependent polynomial transformations to convert one coordinate set into another, not knowing their datum parameters shall be abolished.
5. A map projection providing uniform planar coordinate system over the entire territory of the country which is rather small to be divided into zones. The Lambert conic conformal projection with one or two standard parallels provides a relevant background for detailed analyses and selection of optimal parameters which to be submitted for approval by the authorized government bodies.

Defined in this way, System 2000 would introduce an accurate, consistent and representative set of fundamental parameters, theories and definitions which would provide a proper basis for efficient implementation of advanced surveying and mapping technologies.

3.3. Geodynamic investigations related to EUREF and other regional and local projects

Participation in projects aimed at regional geodynamics is the only way to obtain actual information on recent crustal dynamics which is of a great meaning not only for the academic science but also for geodesy and surveying practice, because the achievable positioning accuracy level demands inherent point velocity data which at present is of the same magnitude as the observation errors.

3.3.1. WEGENER-MEDLAS

It is not possible to distinguish between pure geodetic and geodynamical aspects within the WEGENER-MEDLAS Project realization in Bulgaria which has resulted in the BULREF network (Fig. 1). BULREF is in fact a zero epoch realization of a WEGENER-MEDLAS regional network densification, and any future BULREF campaign, whatever its objective is, will provide an input for geodynamical analyses based on repetitive site occupations.

3.3.2. CERGOP

Upon the decision to associate the country with the CERGOP Central European Regional Geodynamics Project taken at the 6th project conference held in Warsaw, 1995, four Bulgarian EUREF points were included in the Central European Geodynamic Reference Network (CEGRN). In fact only two of them contributed to the CEGRN'96 GPS campaign, performed in six 24 hour observation sessions - SOFI (at that time not a permanent GPS station), and HARM. Data processing took place in Leipzig, where a Bulgarian specialist joined the BKG data analysis team [5].

3.3.3. Chirpan geodynamic network

As mentioned earlier, a 1993 EUREF post-campaign was held at the Chirpan geodynamic network, where observations preceding the 1928 earthquakes (1926) and after them (1958) were collected using traditional surveying instruments and methods. The 13 network points were occupied simultaneously with Trimble 4000 SSE dual frequency receivers for three 8 hour observation sessions. Not longer than 26 km, the baselines allowed for obtaining fixed ionosphere free solutions which provided accuracy at the 1 cm level and better. The network solution was referred to EUREF using observations at GABR, HARM and SOFI sites.

Although not fully consistent, the three available data sets were intercompared in order to assess the changes that occurred due to the regional seismic activity. To get rid of datum dependent discrepancies, the data sets are juxtaposed using a spatial coordinate transformation procedure. In table 3 are given the residuals in northing and easting obtained at each identical point.

The results obtained from the 1926 vs 1958 and 1926 vs 1993 are equivalent within the triangulation accuracy which is quite rough for geodynamical purposes. At this noise level there are no indication for movements and deformations occurred after the 1928 earthquakes. Periodical reoccupation GPS campaigns would certainly yield more informative results [4].

Table 3. Chirpan Geodynamic network: Intercomparison of solutions

PPoint No	1926 minus 1958		1926 minus 1993		1958 minus 1993	
	N	E	N	E	N	E
38	0.146	0.167	0.023	0.146	-0.064	0.011
42	0.158	0.207	-	-	-	-
104	-	-	0.066	0.205	-	-
105	0.013	0.145	0.098	0.070	0.078	-0.026
107	0.262	0.131	0.234	0.082	-0.030	-0.016
108	0.008	-0.233	-0.034	-0.257	-0.029	0.003
109	-0.415	0.189	-0.480	0.096	-0.031	-0.077
110	0.050	0.039	-0.002	-0.042	-0.010	-0.050
111	-	-	0.233	0.244	-	-
112	-0.271	-0.188	-0.185	0.091	0.139	0.110
133	-0.001	-0.146	-	-	-	-
136	-0.142	-0.095	-0.188	-0.068	-0.035	0.037
157	0.067	-0.158	0.034	-0.128	-0.060	0.048
158	0.251	-0.190	0.266	-0.259	0.012	-0.056
160	-0.124	0.032	-0.064	0.003	0.030	0.015

3.3.4. Krupnik geodynamic network

The EUREF'92 GPS post-campaign was performed at the Krupnik Geodynamic Network where various observations have been collected since 1984, in order to monitor horizontal and vertical crustal movements which eventually may occur around the fault crossing nearby. The first GPS campaign here was accomplished in 1990 using a pair of WM101 single frequency receivers, whereas in the 1992 campaign were available 11 Trimble 4000 SST dual frequency sets. The 15 network points were occupied in successive observation sessions connected by two common points and another three EUREF points which provided a junction to the reference frame. The data was processed at BKG by Bulgarian and German specialists by means of the Bernese software, version 3.4.

Within the short time span of two years there were no significant differences detected between both sets of campaign results. However, the available data allowed for testing of various approaches for hybrid data analysis and assessment which led to some practical conclusions successfully used thereafter [4].

3.3.5. Engineering surveys

There are various engineering facilities and installations monitored recently using GPS in a close relation to the EUREF products.

One of them is the Kozloduy Nuclear Power Plant where a network of 85 points and 19 benchmarks is set up to provide a reference for cadastre and future construction activities, as well as for local geodynamical research. Some years before this work was preceded by another investigation where existing triangulation points were reoccupied with GPS with the purpose of analyzing positioning data referred to different observation epochs.

The initial network solution resulted from a combined traditional and GPS data processing. Spatial accuracy of 3-5 mm was achieved mainly due to the precise EDM and levelling data input which strengthened and complemented the dual frequency GPS data set acquired with two Wild System 200 receivers.

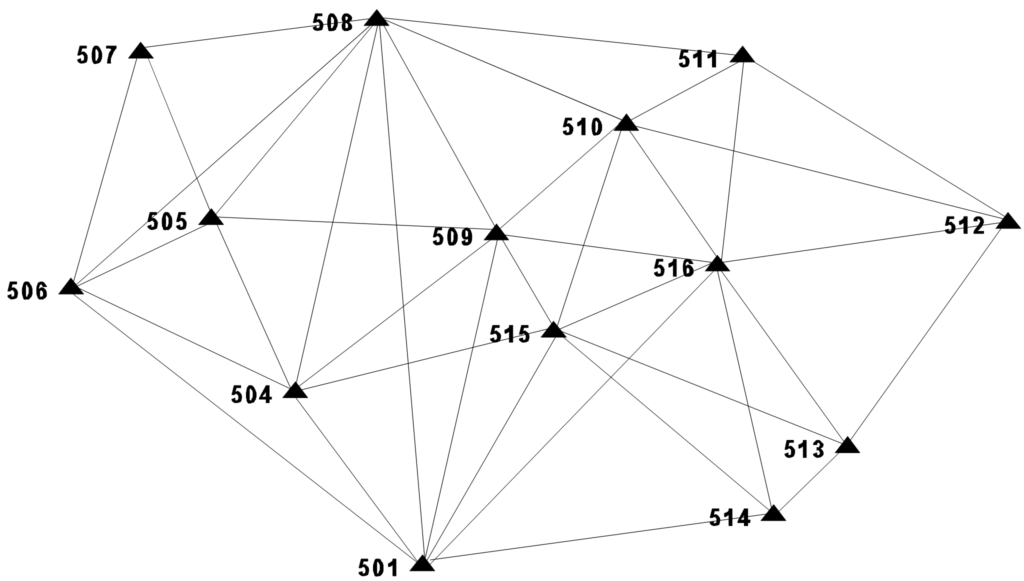

Figure 3. Krupnik Geodynamic Network

The Sofia permanent GPS station was successfully used to monitor deformations of the Kopitoto TV tower near the capital city at 1330 m above the sea level. Analyses of traditional surveying and GPS data has shown 1-2 mm accuracy of shift determination. Practically significant shifts were discovered only in the upper part of the tower mainly due to temperature variations.

4. Conclusion

A huge amount of work has been done to provide all necessary conditions for introducing EUREF into Bulgaria. The EUREF-based BULREF network provides the reference for a radical National Geodetic Network innovation which is urgently needed in many practical and research fields and applications. With the introduction of System 2000 an advanced geodetic foundation would be set up to meet all practical requirements for a long period of time. The multi disciplinary approach would allow for combined data treatment which would result in highly accurate and consistent sets of coordinates, gravity and related data.

The draft monograph is opened for the BKG input which certainly would contribute to improvement of its final English edition.

References

1. ALTINER Y., HABRICH H., MILEV G., MINCHEV M., RASIC L., SEEGER H.: *Results of the EUREF-Bulgaria GPS campaign (1992).* Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 54, Muenchen, 1994, 100-105
2. ALTINER Y., GABENSKI P., HABRICH H., MILEV G., MINCHEV M., SEEGER H., VASSILEVA K.: *EUREF-Bulgaria GPS campaigns final results*. Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 57, Muenchen, 1996, 86-97
3. MILEV G., MINCHEV M.: *EUREF-BUL'92: The EUREF campaign in Bulgaria.* Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 53, Muenchen, 1993, 111-119
4. MILEV G., SEEGER H., MINCHEV M., ALTINER Y., VASSILEVA K., GABENSKI P., RASIC L., MATOVA M., TSONEV TS. : *GPS activities related to local and engineering geodynamic investigations in Bulgaria.* 1st Turkish symposium on deformations, 5-9 Sept. 1994, Vol. 2, 906-920
5. MILEV G., MINCHEV M.: *The European reference system – essence, meaning, introduction and use in Bulgaria*. Geodesija, kartografija, zemeustrojstvo, 1, 1997, 4-12 (in Bulgarian)
6. MINCHEV M.: *Establishing a 3D reference frame in Bulgaria*. Papers of the 4th common conference of NATO WGGG and military topographic services of PfP countries, Bucharest, 3-4 Sept 1997, 236-243
7. SEEGER H., MILEV G., MINCHEV M.: *GPS measurements in Bulgaria related to EUREF and the local geodynamics*. Geodesija, kartografija, zemeustrojstvo, 1, 1993, 24-26 (in Bulgarian)
8. VALEV G., MINCHEV M., CHAUSHEV V.: *System 200 – outline, introducing and dissemination in Bulgaria*. Geodesija, kartografija, zemeustrojstvo, 1, 1999, 3-11 (in Bulgarian)