Renewal of the Reference Network and the Realization of Orthometric Heights Using GPS in Kosovo

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Key words: Reference network, height determination by GPS, Kosovo, EUREF, geodetic datum.

ABSTRACT

The reference network in Kosovo (KOSOVAREF) was renewed and connected to the EUREF Permanent Network (EPN) by long baseline GPS measurements in 2001. The determination of normal-orthometric instead of ellipsoidal heights is needed for the calculation of accurate transformation parameters. The transformation may be used for the referencing of old coordinates and raster data in the new geodetic datum. A homogenously distributed number of network points over the area of Kosovo was provided with normal-orthometric heights by connection to the height information of former FRY IINVT points (Yugoslavia high accuracy levelling, 1970-1973) using special GPS measurements. Based on these additional height connections geoidal heights could be calculated and compared with the European Geoid EGG97 in Kosovo.

ZUSAMMENFASSUNG

Im Jahr 2001 wurde die Erneuerung des Fixpunktnetzes erster Ordnung (KOSOVAREF) sowie dessen Anschluss an das Europäische Referenznetz (EUREF) im Kosovo durch die Messung von langen GPS Basislinien umgesetzt. Die Bestimmung von normal-normal-orthometrischen anstelle von elliptischen Höhen für die Fixpunkte erwies sich für die Berechnung von genauen Transformationsparametern als unverzichtbar für die korrekte Referenzierung vorhandener Koordinaten wie Rasterdaten im neuen geodätischen Datum des Kosovos. Eine homogen verteilte Auswahl von Punkten des neuen Netzes erster Ordnung wurde an die orthometrischen Höhen des jugoslawischen Präzisionsnivellements IINVT (1970-1973) durch eine spezielle GPS Kampagne angeschlossen. Ausgehend von diesem Höhenanschluss konnten Geoidhöhen berechnet werden und mit dem Europäischen Geoid (EGG97) im Kosovo verglichen werden.

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1. INTRODUCTION

One of the main priorities for the United Nations Mission in Kosovo (UNMIK) in re-establishing efficient mechanisms of governance in the Province is the re-introduction of a land and property management system. A functional cadastral system is a pre-requisite for implementing reconstruction activities, upholding the rule of law, promoting economic development, and resolving long-standing conflicts and uncertainties.

On this background the Kosovo Cadastral Agency (KCA) was set up as a responsible body for the development and management of a cadastral and land registration in the Province at a central level.

As one of the initial activities the renewal of the geodetic network as well as the re-definition of the geodetic datum were foreseen.

2. REFERENCE FRAME, TRIANGULATION AND HEIGHT SYSTEM IN THE FORMER REPUBLIC OF YUGOSLAVIA

2.1. Geodetic Datum

In 1924 the Gauss – Krüger conformal transverse cylindrical projection of three-degree meridian zones has been adopted as the official map projection for Yugoslavia of that time. Starting from Greenwich to the east, Yugoslavia was covered by the 5th, 6th and 7th zones having the meridians of 15, 18 and 21 as central meridians. Each zone encompasses 3 of longitude, which means that it spreads 1,5 degrees to the left and 1,5 degrees to the right from the central meridian (Fig. 1).

As ellipsoid a common Bessel definition was used. The local linear scale along the central meridian of each zone was defined as 0.9999. Each rectangular co-ordinate system in the plane of the Gauss - Krüger projection has its origin in the intersection point of projections of central meridian and the equator. Furthermore, a constant value of 500 000 was added to all ordinates in order to avoid negative signs. Finally, the number of the reference zone (5, 6 or 7) is written in front of thus increased ordinate values.

2.2. Triangulation

The former Yugoslavian first order network consisting of totally 395 points is partly destroyed in Kosovo. As a follow up of the war very little documentation about the network itself as well as of the adjustment or the quality of the network is available in Kosovo. All information can be found in Belgrade or Zagreb. The network was generally homogenous with some minor tension from north to south. The number of ruined or unreachable benchmarks is especially large in those areas, which were occupied, devastated and mined during the War. Therefore the actual status of the points (1st and 2nd order) is only partly known.

2.3.1 Austrian Levelling (Klak et al., 1998)

The Military Geographic Institute from Vienna has carried out the first systematic works on the geometric levelling about the territory of the Republic of Croatia at the end of the 19th century and at the beginning of the 20th century, which can be professionally classified as a precise levelling. The data about this levelling have served the purpose of defining the first height system – the normal-orthometric (spherical) height system – that defined the height relations for most part of the territory of the FRY, which was an ingredient part of the Austro-Hungarian Monarchy of that time. The point of origin of that system was defined referring to the mean sea level at the tide gauge in Trieste (Molo Sartorio). This result derived only from an only one-year observation, instead of the full time tide gauge period of 18.6 years. The altitude of the benchmarks of that levelling has an error in the point of origin itself (initial benchmark) of approximately 12 cm (Feil et al., 1992). Nevertheless today's the entire height survey is indicated in this system.

2.3.2 Precise Levelling in the former Republic of Yugoslavia (Klak et al., 1998)

Within the scope of the performance of new works on the geometric levelling, the field revision of levelling lines in the Austrian precise levelling was made in 1946-1960 on the territory of Yugoslavia. These benchmarks served as the basis for all fundamental and practical works about the geometric levelling in the following period. Even the levelling of high accuracy carried out in the above mentioned period was named I. levelling of high accuracy – INVT. It was also intended for the reconstruction of the existing height system, i.e. the system defined by the Austrian precise levelling, and hence, the alignments of the levelling lines coincided in the greater part.

Because of the above-mentioned facts, a new levelling named II levelling of high accuracy - IINVT - was carried out between 1970 and 1973. This levelling was supposed to be used for the establishment of a new height system, and it comprised the territory of the entire former Yugoslavia.

The measurements of the IINVT were carried out systematically, after solid preparations, exclusively with the levels WILD N3, Invar centimeter staffs with double scales, and by using levelling survey arrows instead of slippers.

The origin of this height system has been determined for 3.07.1971 with average sea levels over the period of 18.6 years at five tide gauges along the east coast of the Adriatic Sea, particularly, at the tide gauges in Kopar, Rovinj, Bakar, Split and Dubrovnik.

The data of this levelling are completely processed, analyzed, evaluated and published for the areas of the Republics of Croatia, Slovenia, Bosnia and Herzegovina and the provinces of the

Vojvodina and Monte Negro by the Faculty of Geodesy, University of Zagreb (Bilajbegović et al., 1986). For Serbia, Macedonia and Kosovo it got processed at the Institute of Geodesy, University of Belgrade.

Unfortunately, the levelling alignments of IINVT mostly do not correspond with the alignments of the previous levellings, the Austrian precise levelling and with INVT, which makes better comparison of the benchmark heights between these levellings impossible. Shortly after finishing the IINVT network, the Federal Geodetic Authority (FGU) in Belgrade was closed. The data and documentation was distributed to the geodetic institutions of the FRY. Because of the war the IINVT height system was not consequently and subsequently introduced.

After the phase of IINVT there was no other organized levelling of high precision in the Serbian influenced areas of Vojvodina, Montenegro, Serbia and Kosovo.

3. KOSOVAREF – FIRST ORDER REFERENCE NETWORK

3.1. The new Geodetic Datum

The geodetic datum is defined on the base of the European Terrestrial Reference System 1989 (ETRS89) that was created as a standard for modern national surveys on the continent. Therefore, as reference spheroid, the IUGG GRS80 ellipsoid is used. The origin of the Kosovo datum as well as the projection system is orientated to the former projection system used in the area (origin in the intersection point of the projection of the central 21st meridian at the equator. The Gaussian conform projection in the Gauss-Krueger version according the definition given above shall be used in the future (Kohli et al., 2001). As vertical definition of the datum the definition from IINVT is used.

3.2. KOSOVAREF

The network was established homogeneously over the whole area with general baseline lengths of < 50 km. The distances between the points lay between 15 and 25 km. 22 of the 32 points are points from the existing triangulation network with old coordinates. Up to now there is no overlapping realized with networks in Montenegro, Albania, Macedonia and Serbia. The EPN connection was set up as a main feature of the new network.

All points were checked before the measuring according their quality (checklist) by local experts from Kosovo Cadastral Agency (KCA). Up to 5 point-sites had to be moved in save areas because of mine fields.

All measurements were made in the static mode with Leica GPS receivers 520/530 and with Leica antennas AT502. The points were observed about 2 to 6 hours per session. The sessions of a sector were connected to the next sector/session by using the neighboring main and secondary reference station (Fig. 2). For reliability reasons the second campaign was realized 1.5 week after the first.

The long baseline processing was carried out by the Swiss Federal Office of Topography with the Bernese GPS Software V. 4.2 out of controlled RINEX data files delivered from Kosovo (Wiget et al., 2001).

As tracking stations the permanent EUREF stations of Graz, Matera, Sofia and Zimmerwald were used. Graz and Matera were introduced as fixed control points with a priori sigma of 0.01 mm.

The results of the final solution are of good quality. All the centricity errors are contained in the computation. See Table 1 for the rms values from the coordinate component of the final solution.

Component	**Rms**	**Maximum values (Point number)**
North - South	2.5 mm	12.5 mm (KL01)
East - West	4.4 mm	40.2 mm (DE01)
Ellipsoidal height	8.7 mm	41.0 mm (NO01)

Table 1: Statistics of the GPS-measured 1st order reference Network KOSOVAREF.

To use the coordinate information of former triangulation points as a base for the definition of transformation parameters, it was evident to raise the height component of the new network from ellipsoidal to the comparable level of the normal-orthometric heights. The rotation by x and y shall be avoided. Therefore the connection to the hight level of the second national precise levelling IINVT was realized (see chapter 4). The transformation is used for the referencing of old coordinates and raster data in the new geodetic datum.

For diagnostic reasons of the old survey a plot of coordinate differences was realized by transforming the old coordinates into the new reference frame of KOSOVAREF. The resulting distortion vectors vary from 0.0 m to about 0.6 m (see Fig. 3). These values can be seen as satisfactory and reliable in comparison i.e. with the situation in other European countries (Switzerland: Gubler et al., 1996). Out of Fig. 4 some systematical behavior of vector groups with a similar direction can be found.

Existing coordinate information shall be transformed to the new frame by an affine transformation using finite-element-method. Therefore some investigation of suspicious points will be needed before the definition of the triangle grid.

4. HEIGHT CONNECTION TO IINVT

The measurements concerning X and Y of the reference points were all taken by GPS and evaluated by long baseline calculations with EPN inbound and adjustment. This leads to ellipsoidal (only geometrical influenced) heights for each point.

The connection to the normal-orthometric height level made the inbound of a selection of levelled, former reference points of the FRY levelling system necessary. This methode allowed a more accurate computation of transformation sets.

Totally 23 of 32 1st order reference network points were connected by static GPS measurements of 1-2 hours to normal-orthometric heights from 11 former FRY IINVT points. Where needed excentrums of the height reference points were levelled with a Leica NA 3002. For the GPS connection only points in a height range from about 100 m and a maximum distance of 15 km in relation to a former height reference point were selected (see Schlatter et al., 2001).

Because of short baselines were used the computation of GPS data was done with SKI PRO at KCA as well as the evaluation of the levelling data with Leica LevelPak. The Swiss Federal Office of Topography calculated the geoidal undulations given by the European Gravimetric Geoid 1997 (EGG97) [Denker and Torge, 1997]. The resolution of EGG97 is 1.5 x 1.0 minutes.

Nr	**Name**	**Longitude**	**Latitude**	**Ellipsoidal heights**	**Levelled heights**	**Geoid EGG97**	**h_{ell} - h_{level}**	**h_{ell} - h_{level} - Geoid**
101	BA01	21.275671	42.829020	689.3813	644.199	45.4614	45.1823	-0.2791
102	DE01	20.318920	42.485677	566.3720	522.185	43.7882	44.1870	0.3988
104	FE01	21.129828	42.364003	659.6860	614.667	45.1179	45.0190	-0.0989
105	FK01	21.068957	42.636810	584.7155	539.750	45.1670	44.9655	-0.2015
106	GI01	21.436355	42.465692	640.0816	594.947	45.3328	45.1346	-0.1982
107	GJ01	20.378330	42.358466	483.8429	439.648	43.7765	44.1949	0.4184
108	GJ02	20.541906	42.357375	450.1287	405.916	44.2103	44.2127	0.0024
109	GL01	20.906832	42.644782	663.1543	618.198	45.0870	44.9563	-0.1307
110	IS01	20.454238	42.717407	482.6372	437.726	44.6733	44.9112	0.2379
111	KA01	21.265455	42.215861	806.6284	761.592	45.1123	45.0364	-0.0759
112	KCA1	21.168487	42.646441	666.6692	621.711	45.3395	44.9582	-0.3813
114	KM01	21.576805	42.570233	635.3978	590.268	45.4098	45.1298	-0.2800
115	LE01	20.750187	43.139080	591.1666	545.545	45.7240	45.6216	-0.1024
116	LI01	21.130494	42.583536	601.7465	556.812	45.2013	44.9345	-0.2668
117	MI01	20.855282	42.879902	553.6998	508.387	45.4358	45.3128	-0.1230
119	PE02	20.314648	42.643264	542.6198	497.718	44.4368	44.9018	0.4650
121	PO01	21.203369	42.907363	691.4463	646.297	45.4778	45.1493	-0.3285
122	PR01	21.205834	42.650004	856.0852	811.114	45.4263	44.9712	-0.4551
123	PZ01	20.768352	42.209437	915.3459	870.991	44.4498	44.3549	-0.0949
127	SK02	20.716758	42.771594	759.5223	714.189	45.1401	45.3333	0.1932
129	SU01	20.763979	42.362152	532.5190	488.109	44.4945	44.4100	-0.0845
130	VI01	21.332764	42.333905	537.1835	492.143	45.1772	45.0405	-0.1367
132	ZU01	20.593864	42.826738	916.5042	871.193	45.3194	45.3112	-0.0082

							Mean	-0.0665
							Rms	0.2526

Table 2: Height differences between GPS (ellipsoidal), levelling and Geoid (EGG97).

The evaluation of the measurements showed differences between measuring by GPS and level of about 0.7 – 4 cm on the chosen distances. The mean of this height differences was 2.3 cm.

The differences between the ellipsoidal and the levelled heights should theoretically correspond with the geoidal undulations. Therefore the column "h_{ell} - h_{level} - Geoid" in Table 2 shows the residuals compared to the European Geoid EGG97 in Kosovo. These differences were also plotted onto the map of the geoid (see Fig. 6). From Table 2 it can be learned that no general height shift was detectable. The differences between the ellipsoidal and the levelled heights lay in the range of 44.19 – 45.62 m and should correspond with the geoidal undulations.

Some systematic behavior of the residuals shows Fig. 6. In the eastern part generally a negative difference was detected whereas in the western part it was the contrary. The differences can either be due to the geoid (anomalies, offset and/or slight tilt), which might not be specific enough for these local studies, or due to errors in the levelled heights. Those differences originating from the ellipsoidal heights should be limited to some centimeters.

After some further investigation it was found out that only for three of the eleven used height reference points adjusted IINVT values were available (Fig. 5).

5. CONCLUSION AND FUTURE PROSPECTS

5.1. Reference Network

The new network KOSOVAREF is a nicely usable basis for the reference networks of 2nd and 3rd orders. These networks will be established mainly where needed e.g. in towns and construction areas and shall content reliable and accurate three-dimensional coordinates.

5.2. Height system in Kosovo

Using GPS for height determination in addition to levelling gave satisfaying results within the required accuracy (see also Schlatter et al., 2001).

Considering the poor information and documentation available today on IINVT and its adjustment in Kosovo the following steps on the height system may be taken:

- Out of the information to be collected on IINVT an additional selection of homogenous distributed points for the GPS connection with the 1st order KOSOVAREF has to be measured by GPS.
  - Improvement of the reliability of the heights of the KOSOVAREF (all order).
  - Publishing the data of the normal-orthometric height system for practical application all over Kosovo.
  - Calculation of a well founded new geoid solution for Kosovo besides the modeled solution of EGG97.

- To emphasize the more important principle of the neighborhood accuracy than the absolute accuracy of the connection with the height systems of the adjoining areas of Kosovo is needed.
- For the integration into the United European Levelling Network – UELN – and the definition of a rigid orthometric height system the determination of an accurate geoid by terrestrial or airborne means is needed in future.

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