CONSIDERATIONS ON THE STATE OF ROMANIAN NATIONAL GEODETIC NETWORK

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Abstract:
Achieving National Geodetic Network (RGN) has come over the years a number of stages, starting from astronomical measurements (coordinates, azimuths), continuing with direction and distance measurements in triangulation networks realized by optical then electro-optical instruments , while levelling determinations, supplemented in part by gravimetric determinations, culminating in the last decade with satellite measurements (GNSS).
In the analysis of (national) geodetic networks may be taken into account in particular, aspects of: datum (reference system), coordinates, measurement technologies, types of measurements, processing models, legislative, organizational and economic requirements.
This paper presents relevant aspects of RGN evolution, with emphasis on the last ten years stage in close connection with increased use of satellite technology (GNSS) in geodetic networks achievement at global, regional and national levels.
Keywords: *national geodetic/spatial network, triangulation, levelling, gravimetry, GNSS*

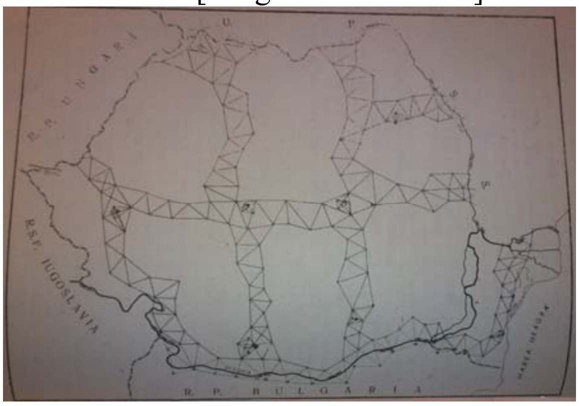
1. Background

1.1 Triangulation network

Romania as European country has developed a national geodetic network (NGN) in accordance with economy, technology and science development on this field. National geodetic network was based before the satellite geodetic era to astronomical determinations (Laplace points) and the concept of "fundamental" geodetic reference data (origin, rotation angles, major semiaxis, flattening), and "fundamental" control points.

Old Romania triangulation, before the 2nd World War, has "Dealul Piscului" (Bucharest) astronomical fundamental point based on the hypothesis of coincidence between the geoid and Hayford ellipsoid and astronomical azimuth on fundamental point.

A second important phase in Romanian NGN development was the phase of first triangulation chains (Ist order; 374 points with 337 from Romania and 37 outside; 8 distance baselines) covering Romania (Fig.1), adjusted in 1956-1958 and 1962 (Fig.2) together with similar triangulation of former socialist countries. The geodetic reference data included Pulkovo fundamental point, Krasovski ellipsoid and astronomical azimuth on fundamental point. Triangulation network of IInd order included 1224 points (337 from Ist order), IIIrd order included 4073 points (1224 from IInd order) and IVth order included 8708 points (4073 from IIIrd order). The triangulation density points was of 1 point/20 sqkm and the precision of about 10-15 cm [Dragomir et al. 1986].



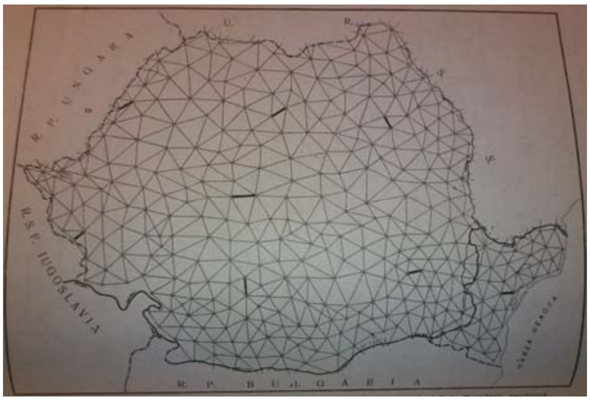


Fig.1 Triangulation network – Ist order (1956-1958) Fig.2 Triangulation network – Ist order (1962) [Dragomir et al., 1986]

A third phase of Romanian NGN development was between 1966-1970 when the triangulation network was improved by new observations (especially new baselines measured with electronic distance instruments; about 80 baselines with length between 15 and 41 km), new adjustments based on new concepts and software development. The main contribution to the realization od NGN was done by Military Topographic Directorate (DTM) and Institute of Geodesy, Photogrammetry, Cartography and Land Use (IGFCOT).

In a fourth phase (1970-1990), Romanian NGN was improved with additional distance measurements including astronomic observations, distance measurements (compact networks for big towns) and angular observations. Romanian NGN was extended in the Danube Delta. In 1984 was performed first Doppler (satellite) campaign in Romania. After 1990, Global Navigation Satellite Systems (GNSS), mainly GPS (Global Positioning System) have been used in Romania in order to develop a new (satellite) geodetic network.

1.2 Gravimetric network

Romanian NGN includes the gravimetric network as base for the realization of the national height reference system. First gravimetric determinations in Romania have been realized in 1947 and 1948 by establishment of the geophysical observatory in Surlari/Caldarusani with tetrapendulum Askania instrument connected with Potsdam international fundamental gravity station (prof.M.Socolescu). Other observations have been performed with instruments as Norgaard (Sweden), GAK (Soviet Union), Sharp and Worden (Canada). After 1950 up to 1957 was designed and realized Ist order gravimetric network including 15 stations on the main Romanian airports. IInd order gravimetric network was design to include 216 stations, but was not finalized. Romania joined IGSN71 (International Gravity Standardization Net). In a second phase after 1976, the Ist and IInd order gravimetric network was re-designed (Fig.3a). Ist order network included 21 stations (+/-0.1mgals) and IInd order network included 223 stations (+/-0.02 mgals). The observations were realized with Worden and Sharp instruments calibrated on a base closed to Brasov (M.Mihailescu and V.Rosca). The results were used for normal height reference system realization in Romania. Normal height corrections were computed on closed leveling polygons. In the same time based on the gravimetric deflection of the vertical, a quasigeoid height was determined for the Ist order triangulation network (I.Diaconu, 1975). After 1990 the Ist and IInd order gravimetric network (Fig.3b) was observed with LaCoste&Romberg instruments by DTM in cooperation with NIMA (USA). The network includes 19 Ist order stations - +/-0.08 mgals and 222 IInd order stations - +/-0.13mgals [Rotaru and Cioancă, 1996].

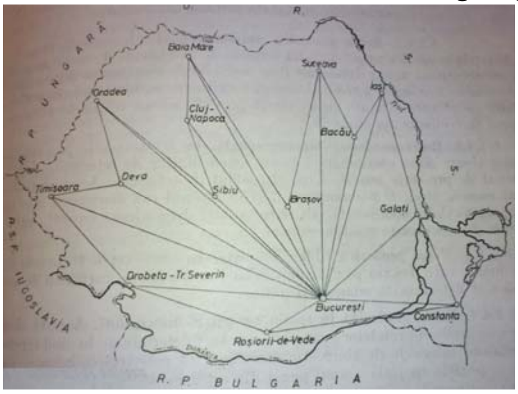


Fig.3a First order gravimetric network (1976)

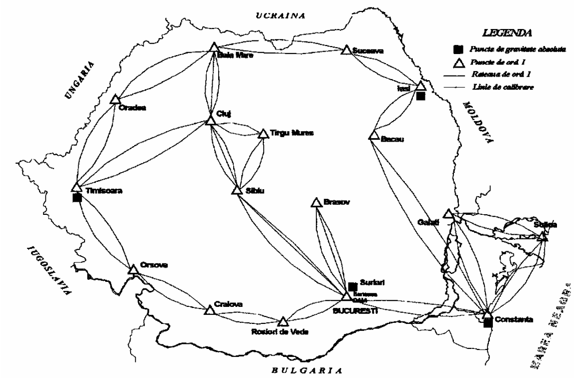


Fig.3b First order gravimetric network (1995)

Recent absolute gravity observations were performed in Romania by foreign teams from Germany (in 1994-1995 for the UNIGRACE project and EUVN project), USA(1996) and Austria (2004). *Gravity data at the present are not sufficient for the development of an (quasi)geoid model with an accuracy of 10 cm or better*. The EGG97 geoid model available from IAG was purchased by NACLR and tested in order to improve it locally by geometric method (local data and ellipsoidal heights from GPS). A new geometric quasigeoid solution was calculated in 2010 (TUCE Bucharest) based on EGG97 and about 600 ground markers with ETRS89 ellipsoidal heights and normal heights (Black Sea 1975 datum). Further efforts should be done for the modernization of the gravity network.

1.3 Levelling network

The national reference system for the heights in Romania is Black Sea 1975 datum. Normal heights are available for the National Leveling Network. The National Leveling Network it is divided in 5 orders (function of precision). The National Precise Leveling Network of I^{st} order consisted in a number of 19 polygons with a length of 6600 km and includes 6400 points with a density of 1 point/km^2. 24 leveling lines establish the connections with neighbour countries: 2 with Ukraine, 1 with Republic of Moldova, 6 with Bulgaria, 10 with Serbia/Montenegro and 5 with Hungary. This network was densified until 32 polygons with levelling networks of II^{nd} -V^{th} order (Fig. 4).

The Romanian contribution to UELN (2000) contains the nodal points of the polygons of first order (65 points) and 89 levelling observations.

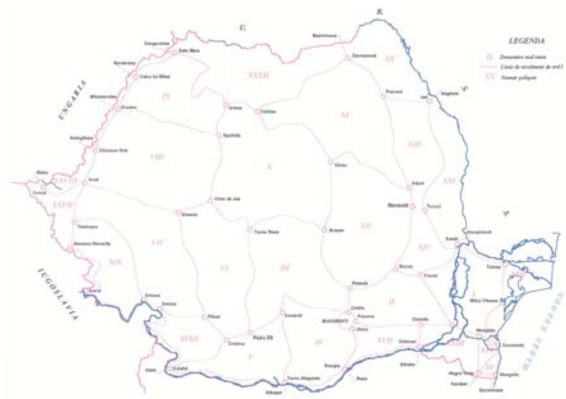


Fig.4. Romanian Ist order levelling network

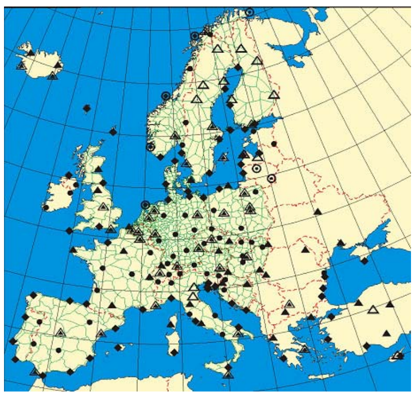


Fig.5 Romanian EUVN stations

The EUVN97 (European Unified Vertical Network 1997) included 4 points from the Romanian Levelling Network: RO01 (Sirca-Iasi), RO02 (Constanta), RO03 (Timisoara) and RO04 (Tariverde – Height 0) points measured with GPS technology and absolute gravity (Fig.5). For these points the known ETRS89 coordinates and normal heights (precise levelling) in Black Sea 1975 datum were determined together with absolute gravity.

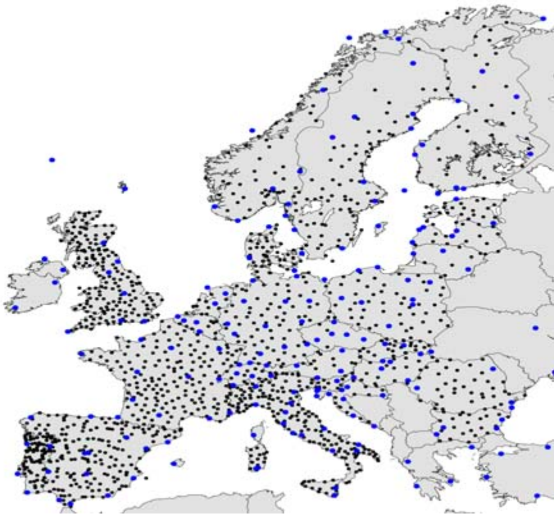


Fig.6 EUVN-DA stations

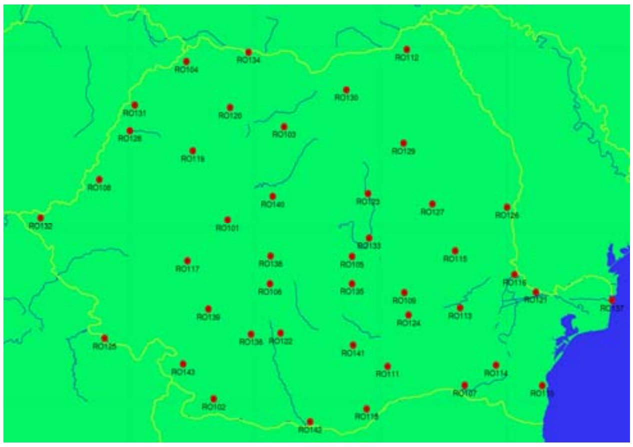


Fig.7 Romanian contribution to EUVN_DA project (2009)

For the ECGN (European Combine Geodetic Network) project in September 2004, Austrian Federal Office of Metrology and Surveying (BEV– Bundesamt fuer Eich-und Vermessungswessen) in cooperation with Romanian National Agency for Cadastre and Land Registration (NACLR) and Military Topographic Directorate, performed an absolute gravity observation campaign in Romania. A number of 4 absolute gravity stations were observed by JILAg-6 absolute gravimeter. Romania participated with such information to the EVRS realization - EVRF2000. After 2000 year Romania further contributed by providing new data including 43 stations with ETRS89 ellipsoidal heights and normal heights in national height reference system (Fig.7). This was the contribution to the EUVN_DA (Densification Action) project with final result the EVRF2007 realization (Fig.6). 25 European countries participated and submitted the data of more than 1500 high quality GPS/leveling benchmarks.

The submitted data was validated and converted into uniform reference frames. The final report was discussed at Technical Working Group meeting and presented at the EUREF2009 symposium, held in Florence (Italy). The results were circulated to all contributing National Mapping Agencies including Romanian National Agency for Cadastre and Land Registration (NACLR).

This action it is continued in Romania by NACLR. For each county it is planned to be realized a number of minimum 5 such stations. Until 2010 there were fully covered a number of 10 counties. New data should be provided periodically to the EUREF for inclusion in new EVRF realizations.

As a final EVRF2007 realization in Romania, a standard transformation parameters were computed by EVRF computing centre from Federal Agency for Cartography and Geodesy (BKG, Germany). These set of parameters realize the transformation of normal heights from Black Sea 1975 System to EVRF2007 (RO_CONST / NH to EVRF2007). Transformation parameters were derived from 43 identical points (UELN nodal points) with a transformation RMS of 0.004 m, and residual deviation between -0.012 m and +0.013 m. A general view of the EVRF2007 realization in comparison with national height reference systems can be seen on the next picture (Fig.8).

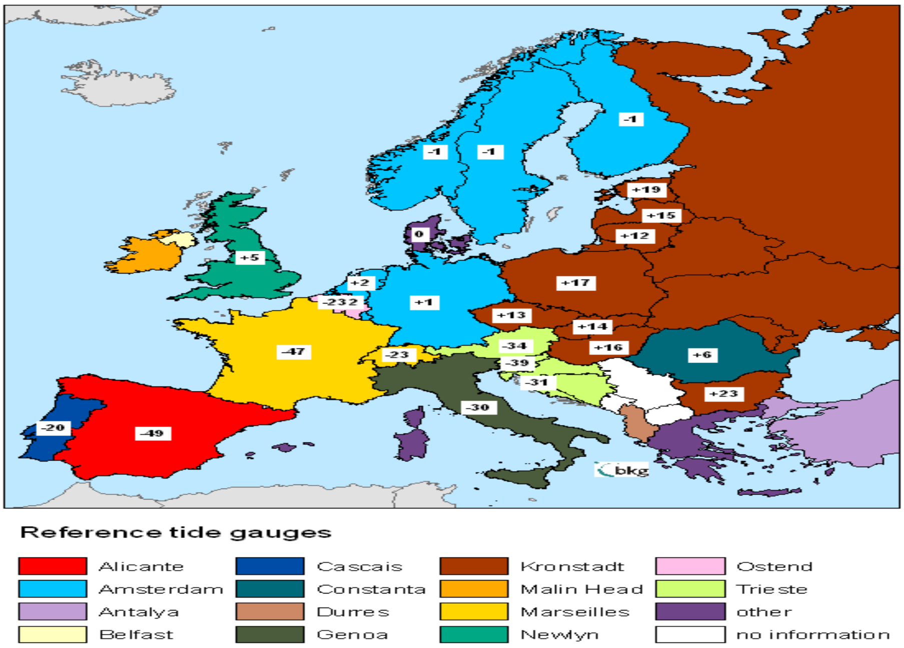


Fig.8 Mean differences between EVRF2007 and national height reference systems

2. European Trends on Coordinate and Reference Systems

At present (after 2000 year) the challenges regarding the lack of availability, quality, organization, accessibility, and sharing of spatial information are common to a large number of policies and activities and are experienced across the various levels of public authority in Europe.

In order to solve these problems it is necessary to take measures of coordination between the users and providers of spatial information. The Directive 2007/2/EC of the European Parliament and of the Council adopted on 14 March 2007 aims at establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) for environmental policies, or policies and activities that have an impact on the environment. The spatial data basis includes the definition and practical availability of specific *coordinate and reference systems* (CRS).

Coordinate reference systems are defined as being *"*Systems for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude and longitude and height, based on a geodetic horizontal and vertical datum".

For the *three-dimensional and two-dimensional* coordinate reference systems and the horizontal component of compound coordinate reference systems used for making available the INSPIRE spatial data sets available, the datum shall be the datum of the *European Terrestrial Reference System 1989 (ETRS89)* in areas within its geographical scope, or the datum of *the International Terrestrial Reference System (ITRS)* or other geodetic coordinate reference systems compliant with ITRS in areas that are outside the geographical scope of ETRS89. Compliant with the ITRS means that the system definition is based on the definition of the ITRS and there is a well documented relationship between both systems, according to EN ISO 19111. For the computation of latitude, longitude and ellipsoidal height, and for the computation of plane coordinates using a suitable mapping projection, the parameters of the *GRS80 ellipsoid* shall be used.

For the vertical component on land, the *European Vertical Reference System (EVRS)* shall be used to express gravity-related heights within its geographical scope. Other vertical reference systems related to the Earth gravity field shall be used to express gravity-related heights in areas that are outside the geographical scope of EVRS.

As was presented above, Romania as EU member should follow the INSPIRE directive and other European standards proposed or recommended by responsible organizations as *EUREF* and *Eurogeographics*. In the last decades geodetic and cartographic activities in Romania were in progress according to the economy and social situation. Economical development in our country after integration into European Union concluded to some positive effects . The National Agency for Cadastre and Land Registration (NACLR) under Ministry of Regional Development and Tourism (formerly under Ministry of Administration and Interior) is the state responsible institution for civil geodetic and mapping activities in Romania. From a self financing public institution NACLR was transformed since 2009 in a state budget institution. NACLR includes the national mapping activities and 42 Cadastre and Land Registration Offices. As research and production institution acts the National Centre for Geodesy, Cartography, Photogrammetry and Remote Sensing. Due to the economical situation in 2009 and 2010, NACLR was reorganized by decreasing the employees number.

3. National Geodetic Spatial Network

According to the global and European trends in the field of modern geodetic networks, Romania followed this trend by promotion and implementation of a new high accurate geodetic network in the time interval 2004-2010. The new geodetic network it is build as an active continuously operating network. As technological equipments the GNSS (GPS and GPS+GLONASS) receivers are included into the network.

Starting in 1991 with first GPS equipments and continued in 1999, when it was installed the first GPS permanent station in Romania (BUCU) at the Faculty of Geodesy - Technical University of Civil Engineering Bucharest in cooperation with Federal Agency for Cartography and Geodesy Frankfurt a.M. (Germany), the new methods of global satellite positioning were introduced in Romania.

In 2001 the National Office for Cadastre, Geodesy and Cartography (reorganized in 2004 as National Agency for Cadastre and Land Registration) installed 5 GPS permanent stations in Braila, Suceava, Cluj, Sibiu, Timisoara (BRAI, SUCE, CLUJ, SIBI, TIMI) as a necessity for precise geodetic measurements in the area. Romania as a CERGOP (Central European Regional Geodynamic Project) country member installed two GPS permanent stations in Craiova and Constanta in 2004 (CRAI, COST). In 2005 the continuously modernization of the National GNSS Permanent Network consisted in the installation of 5 new GPS permanent stations in Bacau, Deva, Baia Mare, Oradea and Sfântu Gheorghe (BACA, DEVA, BAIA, ORAD, SFGH). With their own funds or from PHARE and World Bank, the GNSS network was continuously extended by NACLR in 2007-2010. At the end of 2010 the Romanian GNSS permanent network included 60 GPS and GNSS permanent stations installed by NACLR and one GNSS permanent station installed at the Faculty of Geodesy, Technical University of Civil Engineering Bucharest Bucharest. The EUREF (EPN) station BUCU was introduced into the IGS network since 2005 and was modernized in 2008 with the help of the Federal Agency for Cartography and Geodesy Frankfurt a.M. (Germany).

Other 6 stations were modernized in 2009 by replacing old equipments (Leica System 530) with new equipments (Leica 1200 GNSS+, AR25 antennas).

Romania it is member of the EUPOS (European Position Determination System) organization contributing to the standards adopted by members from 18 Central and East European countries and EUPOS infrastructure by realizing *ROMPOS (Romanian Position Determination System)* based on the 60 GPS and GNSS permanent stations (Fig.9a, Fig.9b).

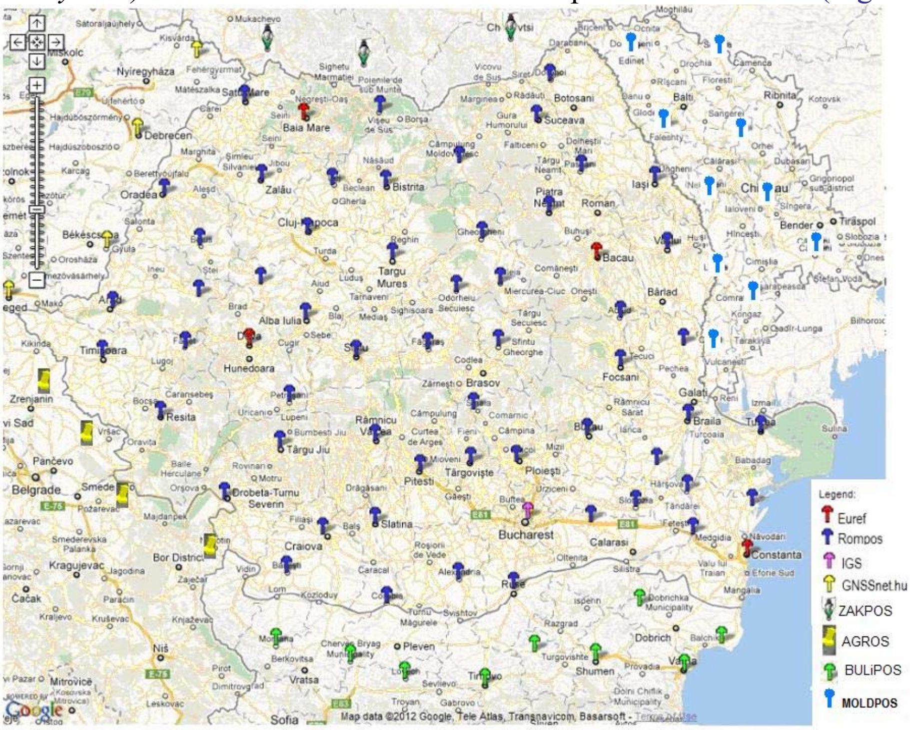


Fig.9a Romanian National GNSS Permanent Network (ROMPOS) and neighbour stations

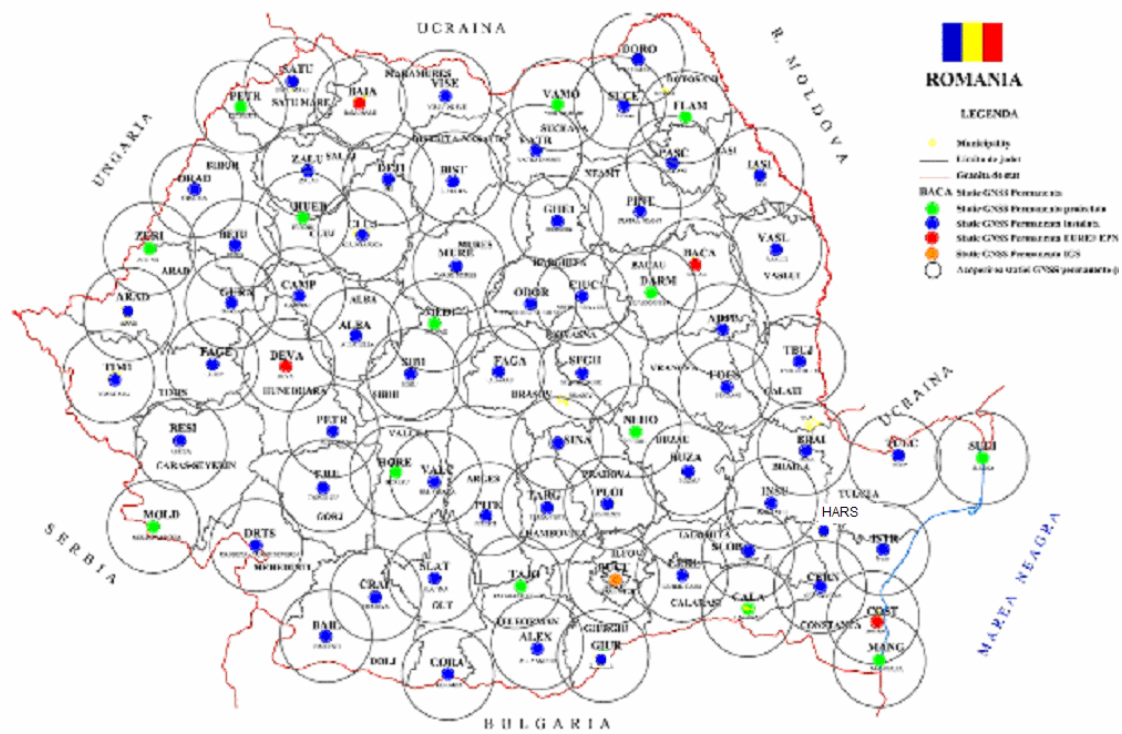


Fig.9b Final Romanian National GNSS Permanent Network (ROMPOS) – 2012 (?)
(red – IGS/EUREF/EUPOS sites; blue – EUPOS sites; green – future sites)

The vector length between the ROMPOS GNSS permanent stations are presented below (Fig.10).

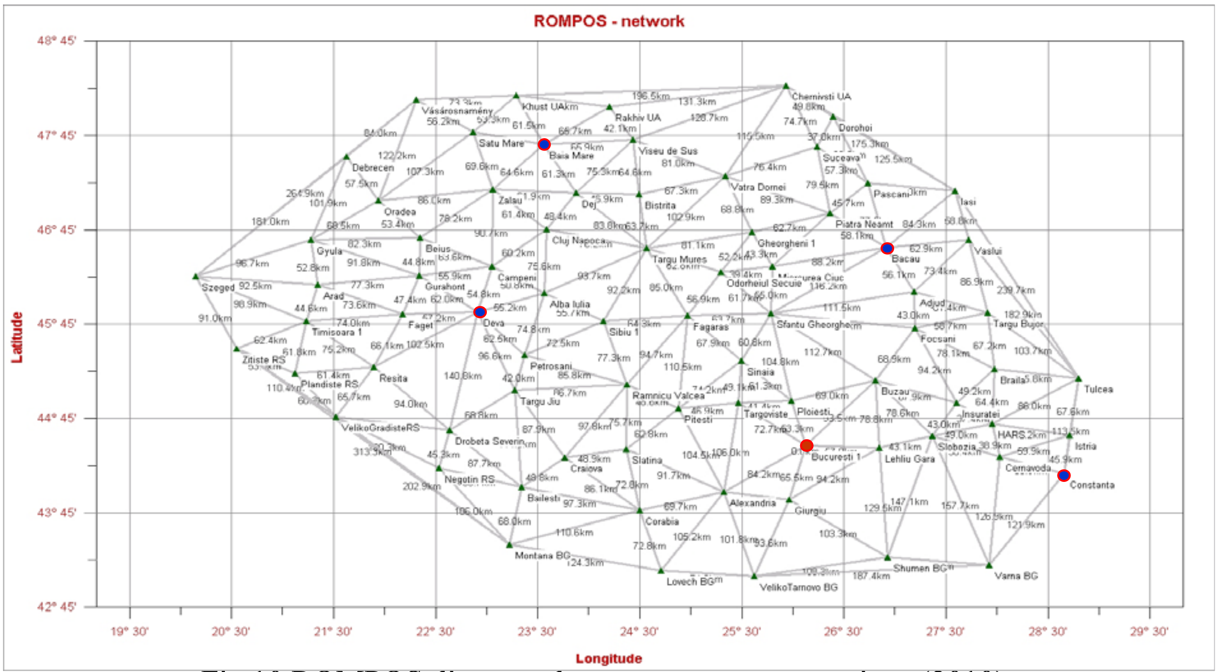


Fig.10 ROMPOS distances between permanent stations (2010)
(red – IGS/EUREF/EUPOS sites ; included stations from BG, SR, HU and UA))

In January 2006, the NACLR integrated in the EUREF-EPN (European Permanent Network) 4 new GPS permanent stations: BACA, BAIA, COST and DEVA as a contribution to the European reference frame maintenance and other special projects (Fig.11). The EUREF-EPN GPS station in Constanta (COST) it is located near to a tide gauge and it is connected with this by precise leveling. The accuracy for the coordinates of the stations are better than +/- 1cm. All stations are Class A according to EUREF-EPN standards.

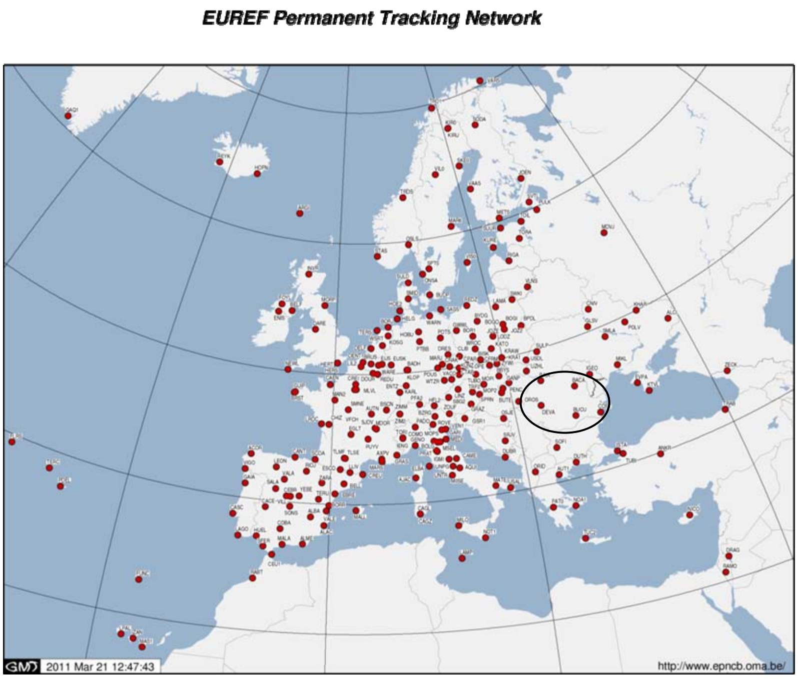


Fig.11 IGS and EUREF-EPN stations in Romania (Bucu, Baia, Baca, Cost, Deva)

The National Spatial Geodetic Network (NSGN) it is defined as the total ground points that have coordinates determined in the ETRS89 Coordinate Reference System and normal heights in Black Sea 1975 reference system, with the possibility to be transformed into the Vertical European System (EVRS). The NSGN (GNSS) was proposed to be divided into "classes" to be separated from the old triangulation network divided in "orders". National Spatial Geodetic Network is structured on classes, using the precision and density criteria, as in the following table (Tab.1).

Table 1. Classification of the NSGN components

Network class	ID	MSE (cm)	No. points/Density/ Distribution	Domain / Observations
National Spatial Geodetic Network Class A0	A0	1.0	*5 GNSS permanent stations (IGS and EUREF-EPN) 1 point / 50000 km^2 Uniform distribution*	- link to the global and European geodetic networks; - regional and local geodynamics measurements, deformation determination, real time positioning services, Meteorology
National Spatial Geodetic Network Class A	A	1.0	*73 GNSS permanent stations 1 point / 3250* km^2 *Uniform distribution*	- link to the class A0 network, - regional and local geodynamics measurements, deformation determination, real time positioning services, Meteorology
National Spatial Geodetic Network Class B	B	2.0	*330 points 1point ./700km^2 Uniform Distribution*	- regional and local geodynamics measurements, high precision topographic determinations
National Spatial Geodetic Network Class C	C	3.0	*About 4750 points 1point/50km^2 Uniform distribution*	- high precision topographic measurements, cadastre; - *partial realized*
National Spatial Geodetic Network Class D	D	5.0	*At least 1point/5km^2 even distribution*	- topographic measurements, densification networks, G.I.S. - *partial realized*

MSE – Mean Square Error of the 3D position determination

Class B network (Fig.12) was observed in 2003 and the results were included into national database in 2005. From the total number of stations about one third have geometric levelling. A number of 86 stations are old triangulation markers observed by GPS with coordinates in national geodetic reference system Krasovski ellipsoid and Stereographic 1970 projection system). Class B network was constrained on the Class A(A0) network. The precisions for the coordinates of these stations are less than 2cm.

Class C network including more than 1000 stations was observed since 2005 till present and it is not yet complete. The precisions for the coordinates of these stations are less than 3cm.

Class D network will be realized in general for cadastre with a no uniform distribution and the precision of these stations will be less than 5 cm.

Fig.12 Class B - National Spatial Geodetic Network (NSGN)
(green – new monuments; blue – old monuments from triangulation network)

4. Conclusions and proposals

4.1 Realizations (+)

With a huge effort of our geodetic ancestors, in Romania was realized the triangulation network at the state of art of those times. It was adjusted and plane positions are available on the old datum (Krasovski ellipsoid, Stereo70 projection plane). The leveling network was developed on Baltic Sea and on Black Sea 1975 datum. By participation on European projects (UELN, UNIGRACE, EUVN, EUVN_DA), national leveling network was integrated in European leveling network and EVRS (with last realization EVRF2007). Romanian gravity network was realized in few phases, but not at the current European or international levels.

With the aid of GNSS technology, a National Geodetic Spatial Network (NGSN) was proposed to be realized and it is partially realized. A big expand was done by realization in the last ten years of Romanian Position Determination Service (ROMPOS) including GNSS reference stations. At present some efforts are dedicated to the multipurpose geodetic ground markers with plane, height, GNSS, gravity (if possible) and time information. This is the trend on present geodetic networks and projects as ECGN (European Combined Geodetic Network) or TEGO (Towards European Geodetic Observatory).

4.2 Drawbacks (-)

At present both plane (triangulation) and leveling networks are quite old and some parts of the ground markers were destroyed or damaged and are not available for practice purposes.

The National Geodetic Spatial Network (NSGN) should use more new ground markers with a better quality and the idea of *multipurpose network*. New leveling and new gravity determinations needs to be realized for modernization of the national leveling network and NGSN realization.

ETRS89 *was not yet fully implemented* as long as it is mandatory only for geodetic networks realized with GNSS technology and pan-European cartographic products. For the rest of positions determination in Romania (for example, cadastre), the old reference system it is still used. A proposal for fully implementation of ETRS89 (realization of NSGN and plane projection on this datum), according to European standards, was realized since 2010, but was not yet adopted until present. The *ETRS89 realization in Romania it is now already old* (based on BUCU reference station) and a new realization should be implemented based on recent EUREF realizations as *ETRF2000 (R05/R08)*. Other countries in Europe have adopted new ETRS89 realizations and implemented new national geodetic reference systems (Bulgaria, Hungary, Moldova, Serbia et al.).

Geodetic and mainly *GNSS national standards should be developed*, especially for user needs (GNSS densification and detail networks, details determination by GNSS) after *adoption of the new CRS in Romania*.

Leveling and gravity observations must be realized for the new spatial network (NGSN). At present (2010) we can observe that no one of the two responsible institutions in Romania for the national geodetic network (NACLR and DTM) do not have any gravimetric equipment. Without such technology a *Romanian quasigeoid* will be not realized at 1 cm accuracy for the GNSS leveling or other applications.

ROMPOS is not fully developed and offered to the users (not all stations purchased and installed, not all possible services offered, not enough promoted for users – old info on website, not finalized data exchange with neighbors, not integrated all neighbor stations, missing detailed ionosphere advisories et al.). In the same time if the *personnel policy* will remain as in present (lack of personnel and rare new update courses), ROMPOS and geodetic activities in general will suffer. The geodetic personnel should be increased and trained and in general more accent on *continuous personnel education*. There are training offers as those of university research centres and others. Research and development department from NACLR should support new developments in geodesy (standards, technologies, publications et al.).

GALILEO global positioning system and *EGNOS* augmentation system should be promoted in Romania by practical means of state institutions (investments in equipments and software), not only by more theoretical means of higher education.

In the same time the *connection of Romanian geodetic authorities with similar authorities* from neighbor and European countries should be maintained close. Participation of Romania representatives on high level events in geodesy (as EUREF, EUPOS, IAG, FIG et al.) and European geodetic projects needs to be realized. Contacts between similar geodetic institutions and professionals (mainly with neighbors and European authorities) should be maintained, otherwise the ”isolation” policy will conclude to drawbacks in this domain.

In conclusion, national geodetic network play a similar role as those of highways in the transportation sector. National geodetic network it is an important infrastructure in Romania and his maintenance and modernization should be continuously considered mainly by state responsible institutions (government, ministry, NACLR, DTM, higher education).

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