Publ. Astron. Obs. Belgrade No. 85 (2008), 181 - 185 *Contributed paper*

HISTORICAL REVIEW OF ASTRO-GEODETIC OBSERVATIONS IN SERBIA

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Abstract. Astro-geodetic determinations of vertical deflections in Serbia began during the first years of 20th century. The first field works were led by S. Bošković. After the 2nd World War, Military Geographic Institute, Department of Geodesy from the Faculty of Civil Engineering, and Federal Geodetic Directorate continued the determinations, needed for reductions of terrestrial geodetic measurements and the astro-geodetic geoid determination. Last years improvements of the astro-geodetic methods are carried out in the area of implementing modern measurement equipment and technologies.

1. INTRODUCTION

The connection between Geodesy and Astronomy is very tight. If one recalls one of the definitions of Geodesy (Vaníček and Krakiwsky 2005):

"Geodesy is a science dealing with measurements and representation of the Earth, including its gravity field, in a 3D time-varying space",

it can be seen that a large part of research is held in the area of determination the gravity field of the Earth. Measurements on obtaining the gravity vector intensity are performed by gravimetric methods, but the direction of that vector can be measured only by astrometric methods.

Hence, the scientific field connecting Geodesy and Astronomy is called Geodetic Astronomy.

The role of Geodetic Astronomy evaluated through centuries. Historically speaking, the first situation astrometric methods were needed for geodetic purposes was in positioning and orientating state reference geodetic networks.

In the past, reference networks were designed as a net of stations with solid foundations, connected one to another so thay formed triangles. Such networks are called triangulation networks. Traditional survey techiques (distance and angle measurements) are relative, so only relative relations between triangulation stations can be calculate. They are, also, called terestrial measurements, because of their dependance on the Earth's surface. To place such network of stations on the Earth surface, some kind of global measurements is needed. Nowadays global positioning and navigation systems are available everywhere and almost to anyone. In the past, the best way to uniquely tie the triangulation network to the Earth as a physical body was using the astrometric methods, which means, astronomical latitude and longitude were measured, and the triangulation network was so tied to a reference surface.

Also, positioning of the network did not suffice all requirements, because of the possible unwanted rotation of the network. To solve that problem, astronomic azimuth between the stations were also measured.

The stations with measured astronomic latitude and longitude are called "geoidal points". If one ore more azimuths to other stations are also measured, such stations are called "Laplace points".

Today, reference networks are, almost exclusivelly, determined by GPS (Global Positioning System). The only situation that terrestrial measurements are really needed is in the field of engineering geodesy, when high precision special control networks shoud be established, usually across small regions. Using GPS as a measurement technique, the problem of positioning and orientating a network does not exist, due to definition of the reference system on a global level.

Still, astronomic azimuths are needed for tracing of long geodetic traverses, terrestrially measured. Another application of astronomic azimuths is in the scope of metrological laboratories, for eatablishing calibration bases for inertial systems, particularly, gyroscopes and gyro-theodolites.

The main current task of Geodetic Astronomy is definition of an Astro-geodetic geoid. Astro-geodetic geoid is obtained by, so called, astronomical levelling. It is a measuring technique which presumes determination both of natural (astronomic) and ellipsoidal (geodetic) coordinates on the same station. Knowing such pair of coordinates, an angle between the verticals on the real equipotential surface (geoid) and normal equipotential surface (reference ellipsoid) can be calculated. With a sufficiently dense field of astronomically determined vertical deflections, the geoid profile across a geodetic network side can be calculated as (Vaníček and Krakiwsky 2005):

$$N = \int_A^B (\xi \cos\alpha + \eta \sin\alpha)\, ds \tag{1}$$

with:

- ΔN - geoid undulation difference
- ξ - meridian vertical deflection component,
- η - first vertical vertical deflection component,
- α - astronomical azimuth from the point A to the point *B, and*
- ds - differential element of the path between the points A and B.

2. FIRST ASTRO-GEODETIC WORK IN SERBIA

First astro-geodetic research began with the scientific work of general Stevan Bošković at the Pulkovo observatory, where he examined the discrepancy of geodetic and cartographical data obtained in Serbia and neighbouring countries. He supposed that the reason of that was the existance of opposite vertical deflections in those countries. The task was to confirm the hypothesis by a number of astro-geodetic determinations of astronomical coordinates throughout Serbia.

Bošković performed his measurements between 1900 and 1911 (Bošković 1952). During that long period, 30 latitude and 30 azimuths were measured. Latitudes were measured using Pevtsov and Tsinger methods, and the azimuths were determinated indirectly, by observing Polaris in an arbitrary hour angle.

For that long term measuring campaign he prepared two universal instruments Kern, with the complete equipment for two measuring crews:

- 12 chronometers,
- aneroids, and
- thermometers.

The ephemerides of pairs of stars, needed for time determination for Tsinger method, were calculated, as well as ephemerids of pairs of stars used for Pevtsov method.

The idea was to perform astro-geodetic measurements in the same time when geodetic measurements of the angles in the first order triangulation network was made. The stations on the highest mountain peaks and the stations in river vallies were picked for astro-geodetic work, because Bošković correctly deduced that, in that way, the best representation of geoid distribution could be obtained.

Unfortunately, those years were very bad for Serbia, because of numerous wars. Since Bošković was also a general in the Serbian army, the work on astro-geodetic determinations had to be canceled several times. These were the reasons that huge observing material could not be processed.

During the wars 1912-1920, there was an urgent need for topographic surveys of the country. The whole observing material was, even, carried through Albania to Corfu, during the World War. Those were all the reasons processing of astro-geodetic measurement data was finished in 1952. Finally, it was showed that Bošković's presumptions were correct, and the half-century long work was completed successfully.

3. DETERMINATIONS BETWEEN WARS

Measurements between two World Wars were held by Military Geographic Institute (MGI). Since general Bošković was a member of the Institute, that work was a kind of continuance of his earlier measurements.

The main tasks of MGI, in the sense of astrometric determinations, were (Bratuljević et al. 1995):

- Meridian arc measurements,
- Measurements of the mean parallel 45°, and
- Determinations of Belgrade longitude.

Meridian arc measurements were performed during the campaign of determination of the meridian, from the Northen Sea to Mediterranean. Measurements on determination the meridian and parallel were held within the scope of International longitude determination campaigns in 1926 and 1933.

Also, during the mentioned campaign, organized by IUGG (International Union For Geodesy And Geophysics) and IAU (International Astronomical Union), the determinations of Belgrade longitude were performed using a transit circle, a zenith-telescope and a universal instrument.

About 40 points were determinated in that period. There were a lot of documented data about measurement methods, instruments and operators. However, results for only 21 points were published in the reports, probably because other data was not processed then. On the other hand, the source data are missing. It is assumed that the material was lost during WW2.

4. AFTER WW2

Institutions engaged in astro-geodetic observations after WW2 were (Bratuljević et al. 1995):

- Military Geographic Institute (MGI),
- Federal Geodetic Directorate (FGD),
- Astronomical Observatory, and
- Institute of Geodesy.

According to the conclusions of the First Congress of geodetic engineers and surveyors held in Zagreb in 1953, the astro-geodetic observations should be continued, in order to assure good foundations for correct orientation of Yugoslav trigonometric network. Also, the network should be incorporated into the European Trigonometric Network.

The first astronomic group was formed in MGI in 1952. The group consisted of two officers, who were also geodetic engineers, and ten officers with military education only. They attented a theoretical course in the field of geodetic astronomy. First determinations started in 1954, by measurements on Laplace points.

A universal instrument and a transit, both manufactured by Ascania, were used for the campaigns. Astronomical latitudes were determinated using Talcott's method, astronomical longitudes using the method of meridian transits, and astronomical azimuts by observing Polaris in an arbitrary hour angle.

Until 1960 14 double and 5 single Laplace azimuths were measured. In 1962 control measurements at Cer and Jautina stations are made. This time, a Wild T4 was used for the campaign.

For the latitude determinations, at least 33 (and most 453) Talcott pairs were measured. Determinations of the astronomical longitudes were made in 10 to 34 meridian transits. The azimuths were observed in 15 to 28 measurements series.

At geoidal points, latitudes are measured by using Talcott's method, with 26 to 63 Talcott pairs per point. The method of meridian transits was used for longitude determinations, and at least 10 pairs were observed per point. Maximum number of meridian transits was 15. From 1961 to 1969, 68 geoidal points were determinated.

FGD determinated 24 Laplace points, in the period between 1956 and 1964. From 1962 to 1973, another 10 geoidal points were measured. Latitudes were measured with 31 to 177 pairs of stars, and longitudes with 13 to 26 pairs.

All measurements, both MGI and FGD, met the accuracy requirements of International Association of Geodesy (IAG).

5. CURRENT RESEARCH

For a long period, geoids were mostly obtained by gravimetric methods. The reason was the complicated field procedure of astro-geodetic measurements. Today, the astro-geodesy becomes popular again, due to advanced equipment incorporated into measuring systems.

The problem of obtaining ephemerides of stars in near real time is solved by intensive use of laptops. Time-keeping can be done by using cheap GPS micro-controllers. The problem of huge instruments also is minimized, because of the portability of modern geodetic equipment.

The research on the astro-geodetic methods at the Faculty of Civil Engineering, Department of Geodesy and Geoinformatics stands on improving measuring systems. Two different systems are examined.

The first of them is devoted to automation of equal zenith distances method. The system consists of Ogrizović (2002):

- a motorized theodolite, as an optical instrument,
- GPS micro-controler, as a time-keeping system, and
- a notebook, for registration purposes.

The registration of star transits are performed manually.

The other measuring system deals with observations of zenithal stars. This system has the following subsystems (Ogrizovć 2007):

- Zenit-lot (an instrument used in applied geodesy for control of high engineering object verticals),
- CCD camera for star tracks registration,
- GPS micro-controller, and
- a notebook computer.

The next step of advancing the systems is raising the integration level of modular systems. The accuracy of achieved results should be improved by incorporating electronic levels for interpretation the horizontal surface. With the current state of the equipment, two to three points can be observed and processed per night, which is a great improvement compared with classical measurement procedures.

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