Establishment of GNSS calibration network

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***Abstract*— It is important to always have measuring equipment which most important parameters and errors are known. For GNSS receiver antennas one of the crucial information for high precision measurement is the location of the true phase center, in relation of its theoretical location. To determine this, a calibration network is necessary. In this paper the process of establishing such network will be presented.**

I. Introduction

It is important to know that the GNSS receivers we want to use for extreme accuracy (sub cm) measurement are calibrated or not. Doing calibration is possible on certified places but if we want it for technical reasons, it is possible to create our own calibration network, which can give the same benefits, but without certification [1] [2].

II. GNSS systems

The Global Navigational Satellite System is able to perform positioning, timing and navigation by being in contact with "artificial moons" if their position is known. Based on this, we can create a reference system from which we can later extract the necessary data. The operation of GNSS gives us access to different raw data, which we can store for our purposes or possibly further process. These raw measurement materials can be phase values, code distances or doppler numbers [4].

Figure 1. NAVSTAR GPS

Figure 2. GLONASS logo

There are different base-systems within GNSS systems.

The GPS system (Fig. 1.) was created and maintained by the United States in the 1970s. Once completed, its primary task was to meet military needs using 24 active satellites.

GLONASS (Fig. 2.) is the result of developments in Russia (first launch occurred in 1982, during the Soviet era), its structure is similar to its American counterpart and can be considered of a similar standard [5].

Europe has not lagged its competitors either, creating the Galileo project in 2005 [6] [7] [8].

This proprietary satellite positioning system provides EU Member States with positioning independent of the other systems.

Nowadays, the development of technology has brought inevitable needs and upgrades. As a result, they started to build a modern location network in Hungary as well, to provide real-time corrections for applications in need of more precise positions.

III. Calibration

The cornerstone of this research was the process of calibration. By performing the calibration, a connection was established between the actual properties provided by the measuring device and the actual quantity to be measured. During calibration, the measurements are performed by comparison with a special, standard quantity. The standard is an extremely accurate value. After the process is completed, a calibration certificate and reports could be prepared [12].

It is important to distinguish between authentication and calibration. Certification is a legal, i.e. official activity, which can be performed only by authorized persons, for which an official document, a certificate of authentication is issued. In contrast, calibration can even be performed by the owner of the device, for example, if the manufacturer requires periodic calibration to enforce the warranty or guarantee [13].

When calibrating GNSS antennas, we are talking about creating a model that determines the position of its phase center. The location of the phase centers of the various antennas is usually given by the manufacturers relative to a reference point. This value should be used in calculations to reduce the potential for error [14].

GNSS calibration begins with a 6-hour measurement where the measured results are processed in 30-minute parts because the National Authority (Lecher Tudásközpont) requires the longer measurements to breake down to fast static-like portions, to calculate standard deviation between them [15]. So the measurement was processed in 12 parts. Vector calculations were performed for these measurements to obtain the components, average them, and plot the differences between the averaged value and the value considered correct from the result, between all the possible combinations of the three pillars and the reference permanent stations

IV. ESTABLISHING CALIBRATION NETWORK

The created newtwork is located on the top of the southern wing of Institute of Geoinformatics. Three pillars were placed there during its construction (we can id them as: East-Central-West), because it is on ideal place if we want to conduct orientational measurements. On the pillars - as a center - a hilti nail was fixed (Fig. 3.). These have limited use (with the help of a pillar stand only) to centrally place a GPS receiver or even a total station on them.

Figure 3. – The top of the pillar

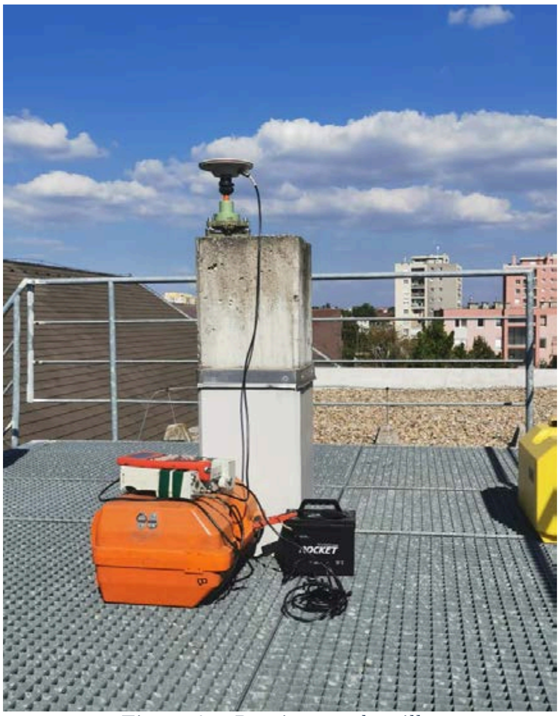

Figure 4. – Receiver on the pillar

Therefore, in addition to the existing marks, an eccentric standard threaded instrument screw has been built into the pillar, which is suitable for placing an instrument base on them.

The network was determined in two ways, the first was by GPS technology. 3 Leica 500 GPS receivers were placed on the 3 pillars (Fig. 4.).

At least one of the receivers measured continuously over a 6-hour time interval, while the other two typically operated on each pillars for a minimum of 3-4 hours (the duration was limited due to the capacity of the batteries), in paralell of course with the permanent station called Székesfehérvár.

The measurement itself could have been done by using only one GPS receiver, measuring 6 hours at the eastern point, for example, then obtaining a vector between the eastern point and the Székesfehérvár point, then measuring 6 hours at the western point, thus obtaining a vector between the western and permanent station and so on, but if its possible to use multiple numbers of identical receivers it is favorable to perform the measurements at the same time on all so to reduce any errors that could arise otherways [18].

In addition to reducing the combined measurement time of the network (one measurement period lasting more than 6 hours each), it also had the advantage that discreate vectors were obtained for the three pillars not only from Székesfehérvár, also between them. This is also more advantageous, because in this way superfluous measurements are availabel for all determinations, so by equalization it is possible not only to determine the network points coordinates, their reliability values also [17].

These measurements were performed for three consecutive days. During the establishment of the network, the measurements with GPS receivers took place at different times of the day on all three days to reduce errors caused by unfavorable satellite constellations, which can occure some time of every day, so by changing time of day the satellite geometries were also different for every measurement. There were of course overlaps between thr 6 hours periods, but the starting time of the measurements were fundamentally different.

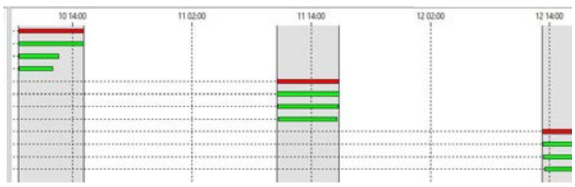

Figure 5. – Intervals of the receivers

The first measurement period was started on September 10, 2020 ~ 8:30. An instrument (KEL) and SZFV were then measured until 15:05, KOZ until 12:35, and NYU until 11:58. The second measurement day, September 11, 2020, started at ~ 10:30. Then, table shows (10. figure), the measurements were successful at almost the same intervals (~ 6 hours). In the third period, on September 12, 2020, receivers were started around 13:15. Here, similar durations were as in the first period (Fig. 5-6.).

Point Id	Start	End	Durat...	Height ...	Antenna Type
SZFV	09/10/2020 08:29...	09/10/2020 15:05...	6h 36' ...	0.0000	AR20 LEIM
KEL	09/10/2020 08:31...	09/10/2020 15:05...	6h 34' ...	0.1765	AT502 Pillar
KOZ	09/10/2020 08:34...	09/10/2020 12:35...	4h 00' ...	0.1752	AT502 Pillar
NYU	09/10/2020 08:36...	09/10/2020 11:58...	3h 21' ...	0.1770	AT502 Pillar
SZFV	09/11/2020 10:32...	09/11/2020 16:48...	6h 16' ...	0.0000	AR20 LEIM
KEL	09/11/2020 10:34...	09/11/2020 16:48...	6h 13' ...	0.1765	AT502 Pillar
KOZ	09/11/2020 10:38...	09/11/2020 16:44...	6h 06' ...	0.1752	AT502 Pillar
NYU	09/11/2020 10:42...	09/11/2020 16:33...	5h 51' ...	0.1770	AT502 Pillar
SZFV	09/12/2020 13:15...	09/12/2020 19:18...	6h 03' ...	0.0000	AR20 LEIM
KEL	09/12/2020 13:17...	09/12/2020 19:18...	6h 00' ...	0.1765	AT502 Pillar
KOZ	09/12/2020 13:22...	09/12/2020 17:41...	4h 18' ...	0.1752	AT502 Pillar
NYU	09/12/2020 13:28...	09/12/2020 17:39...	4h 11' ...	0.1770	AT502 Pillar

Figure 6. – Durations of the recievers

In the first step, these results were calculated one day at a time. To perform the vector calculation and equalization, Leica Infinity software suit was used, It should also be mentioned that the vector calculation was performed with the RTKlib open source processing program.

V. PROCESSING

The raw measurement results were read from the receivers and downloaded from the permanent station were loaded in RINEX format into the Leica Infinity program for all 3-day static measurements. Four RINEX files were available for every day. One contained the results of the Székesfehérvár permanent station and the other were the measurements on the pillars. The header of a measurement is shown on the following, 7. figure:

```
KEL_2540.20o – Jegyzettömb
Fájl  Szerkesztés  Formátum  Nézet  Súgó
     2.11           OBSERVATION DATA    G                   RINEX VERSION / TYPE
LEICA GEO OFFICE 8.4                    12-9-20 21:05       PGM / RUN BY / DATE
                                                            OBSERVER / AGENCY
KEL                                                         MARKER NAME
KEL                                                         MARKER NUMBER
0                   LEICA SR530         5.10                REC # / TYPE / VERS
                    LEIAT502                                ANT # / TYPE
  4119992.8080  1372038.0850  4656165.3127                  APPROX POSITION XYZ
        0.1850        0.0000        0.0000                  ANTENNA: DELTA H/E/N
L1PhaOff:   0.0683  L2PhaOff:   0.0712                      COMMENT
     1     1                                                WAVELENGTH FACT L1/2
     4    C1    L1    P2    L2                              # / TYPES OF OBSERV
  2020     9    10     6    31   30.0000000     GPS         TIME OF FIRST OBS
  2020     9    10    13     6    0.0000000     GPS         TIME OF LAST OBS
    18                                                      LEAP SECONDS
    21                                                      # OF SATELLITES
          C1    L1    P2    L2                              COMMENT
   G 1   962   962   952   952                              PRN / # OF OBS
   G 2     0     0     0     0                              PRN / # OF OBS
   G 3   747   747   747   747                              PRN / # OF OBS
   G 4   349   349   342   342                              PRN / # OF OBS
```

Figure 7. – The header of a measurement

As a result, 18 vectors (6 from each day) with their 3-3 components were calculated (Δx, Δy and Δz). The 6 vectors were constructed according to the following scheme (based on Figure 9): KEL-SZFV, KOZ-SZFV, NYU-SZFV, KEL-KOZ, KOZ-NYU, KEL-NYU. Since redundant measurements were preset, it was possible to adjust the GNSS network.

The adjustments were performed both as a free network and also as a fixed network. In the latter case, the coordinates of the permanent station were accepted as fix. In the first case, all coordinates can get corrections, in the second case the permanent station does not. The latter solution will be considered final at a later date

VI. ESTABLISHMENT OF A HORIZONTAL AND ELEVATION NETWORK WITH MEASURING STATION AND LEVEL

Precise leveling was also performed on the pillars. The relative height difference between each was determined by standard, precise-level leveling method with a precision of 0.1 mm.

The pillars were also measured at 4 locations (screws, nails and 2-2 points on the concreate surface of the pillars), of which we used only three in our measurement.

9.

VII. HORIZONTAL NETWORK

Figure 8. –Top of the GEO – Measurements with Geomax

Measurements were performed with a Geomax total station on the three pillars and one external point (Fig. 8-9.). Direction and distance measurement were performed in one round in one telescope face. The measurement was conducted from an excentric position to reflector prisms placed on the pillars at the precise horizontal location of the GNSS receivers, and also to points on the permanent station. The surrounding points with known EOV coordinates (typically church towers) were also included in the definition of the network, so that we can later use them to clearly insert the network into the EOV system. The network was adjusted as a free network.

The calculation was performed with GeoCalc. GeoCalc is a Desktop GIS application that can read GIS data stored in different digital formats, different projection a system,

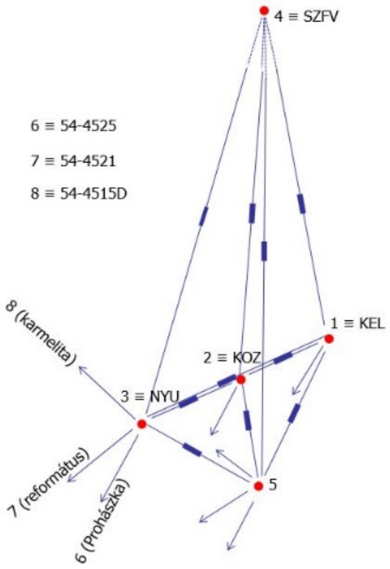

Figure 9. – The free network

and display them as thematic maps, print them in a suitable format [17]. As a result, we obtained coordinates and mean errors.

The network was also adjusted as a vertical network, so that the height of the middle point was captured (-2.3694m). This deviation, as mentioned before, follows from the eccentricity of the phase center that was identified as a deviation in the vertical sense (Fig. 10.).

	Wild csúcs	Csavar	Hilti	Pillér-festé
	Helyi Magasság			
1	99.7047	99.5382	99.5329	9
2	99.7032	99.5358	99.5319	9
3	99.7226	99.5519	99.5489	9

Figure 10. – Vertical network results

VIII. CONCLUSIONS

In the sense of having precise measurement tools, it is not always necessary to find a company which offers certified solutions for calibrations. In many cases it is possible to make similarly precises calibrations by and for ourselves by creating a suitable location. In this paper a case was presented in which a custom built GNSS calibration network was established, measured and the results were adjusted with high precision so in the future conducting GNSS antenna calibration would be possible any time.

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