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Advanced method for station point control accuracy to monitor the behaviour in service stage of civil engineering structures using geodetic satellite technology

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***Abstract* — The monitoring of important engineering buildings is mandatory and necessary especially in crowded urban areas. Achieving a stable and optimal monitoring network leads to a more effective time monitoring of objectives through the use of satellite methods. Satellite geodetic technology along with emerging technologies is a modern way to get data on civil buildings monitored with reasonable accuracy. Thus, the fast evolution of communication technologies allowed and developed several satellite constellations throughout the Globe at the same time, depending on the needs and economic power of owners. In the present scientific paper, we will describe an analysis of the accuracy of data obtained with the use of satellite technology for monitoring the behavior of an engineering building using Romanian Positioning System (ROMPOS) based on satellite systems such as: Global Navigation Satellite System (GNSS), Russian GLONASS and European Galileo, but also on GNSS permanent stations, obtaining real-time data in the ETRS89 European Coordinate System. The aim of this paper is to compare the use of the Global Positioning System (GPS) and GLObalnaya NAvigatsionnay Sputnikovaya Sistema-GLONASS, Chinese Navigation Satellite System – BeiDou, both individually and simultaneously to determine the control points of the monitoring network. The precision of station points determining for an engineering structure is important, and in the case of the use of satellite technology it can be influenced by multiple factors that will be presented in the paper. The accuracy of the station coordinates of the selected target is given by integrating both satellite constellations by increasing the number of satellites used, obtaining a more accurate position with greater visibility to them. It is an engineering structure, viaduct type, over 50 years old, with a length of 1.3 kilometers. The objective is in the North-West part of Galati, Romania and represents an important access road connecting Galati city to the platform of ArcelorMittal steel company requiring a regular observationeven a permanent monitoring.**

Keywords—*GPS, GLONASS, Bei Dou, Civil Engineering, monitoring behaviour in service stage, station points control.*

I. Introduction

The monitoring of engineering buildings behaviour in service stage is a extremely complex process and requires special monitoring tools. Surveying equipments with the evolution of technology and society have seen a significant development which includes among others the use of renewable energy (I. Alecu et all, 2014). The determination of spatial displacements of engineering structures is currently done using modern methods, among which we can list the satellite technology (D.I. Morariu, and D. Lepadatu, 2017).

Global Positioning System dates back to the Sputnik era when researchers used radio signal changes to track satellites, a phenomenon called "Doppler effect". At the beginning of the 1970's, the Department of Defense (D.O.D) from Unitated States of America (U.S.A) wanted to provide a stable satellite navigation system. The first satellite navigation system launched in 1978 is called NAVigation System with Timing And Ranging (NAVSTAR). It has become fully operational in 1993. The GPS now offers two levels of service: The Standard Positioning Service (SPS) that uses the pseudo-random code (C/A) on L1 frequency and the Precision Positioning Service uses the precise code P (Y) with frequency L2. NAVSTAR constellation includes 32 satellites, of which only 31 are functional (D. Lepadatu, 2016) (D. Lepadatu, et all. 2014) (R. Abdulmajed, and R.A. Abbak, 2017) (J. Neuner, 2000).

Instead, GLObalnaya NAvigatsionnay Sputnikovaya Sistema (GLONASS) became partially available after the collapse of the Soviet Union. Since February 2017, the satellite system is not at full capacity but is kept in constant mode and remains operational with 21 satellites (D. Lepădatu, 2016, a) (D. Lepadatu, et all , 2014) (J. Neuner, 2000).

On the other hand, the Galileo European System is connected to the GPS / NAVSTAR and GLONASS satellite constellation to provide a high precision of determination of point positioning. The reference and coordinate system used is ETRS89 (European Terrestrial Reference System), consisting of 30 satellites. The Galileo System is considered superior to the GPS (Figure 1) because it provides horizontal and vertical measurements with a precision of 1 meter (D. Lepadatu, 2016) (D. Lepadatu, D. Covatariu, L. Judele, G. Săndulache, A.R. Roșu, M. Diac, 2014) (J. Neuner, 2000).

Figure 1. GPS System [5]

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The Chinese Satellite Navigation System is called BeiDou (BDS). It consists of two separate constellations. The first is called Experimental Navigation System through Satellite BeiDou or BeiDou-1 and contains three satellites offering limited coverage of navigation services. The constellation was withdrawn in 2012.

The second generation of the BeiDou Navigation System (BDS), also known as COMPASS or BeiDou-2, became operational in China in December 2011 with a partial constellation of 10 satellites in orbit. Provides services to Asia-Pacific customers (Lepadatu D., 2016, a).

In 2015, China began building the third generation (BeiDou-3) in the global constellation. The first BDS-3 satellite was launched on March 30, 2015. Since January 2018, nine BeiDou-3 satellites have been launched. BeiDou-3 will have 35 satellites and will provide global services at its completion in 2020. After complete accomplishment, BeiDou will provide a global satellite navigation system to the Global Positioning System (GPS) and is expected to be more accurate than GPS.

The Global Positioning System in Romania is represented by ROMPOS (the Romanian Determination Position System) and has been developed by the National Agency for Cadastre and Real Estate Advertising (ANCPI). The institution has carried out the modernization of permanent measuring stations based on GNSS (Global Navigation Satellite System) satellites, thus forming permanent GNSS stations. The signals they receive are GPS (U.S.A), GLONASS (RUSSIA) and in the future will be the European GALILEO. The system was launched in 2008, providing the necessary informations to determine the real-time position of 0.5 meters (Lepadatu D., 2016, a).

The advantages of using the three satellite constellations while reading the position of a point can be: availability of a larger number of satellites, satellite geometry is improved, the determination of a point is made more precisely and with greater accuracy, avoiding signal loss.

In the following section it will be described the method of determining the position of the control points of the monitoring network in time of the behaviour of the chosen objective using satellite technology.

Also, it will be presented the accuracy of the satellite system for each determined control point using each constellation individually, as well as by associating them. Finally, the advantages and disadvantages of the method used to monitor the chosen objective will be discussed.

II. Satellite method for monitoring behavior in service stage

Monitoring behaviour in service stage by topographic methods using the satellite technique from thi present scientific paper will be done for a engineering structure viaduct type. The objective is the longest viaduct (Figure 2, 3) in Romania. Built between 1968-1970 on 15 high pillars (Figure 4) of 60 meters high, it has experienced from the beginning multiple settlings due to the swampy ground on which it was built.

Figure 2. Viaduct – Combinatului Street

Figure 3. Viaduct – sky view

Figure 4. Viaduct – pillar view

Vertical spatial displacements were produced also due to the significant earthquakes of 1977, 1986 and 1990, but also to the heavy traffic that caused the structure to weaken. Therefore, the permanent monitoring of the objective is recommended to be done by using modern and accurate surveying methods (Lepadatu et all. 2016, b).

We are proposing a monitoring behaviour in service stage network made up of monitoring marks on the viaduct, control points, station points from which we will read the vertical movements of the structure and the orientation points with known coordinates. The location of the viaduct marks (Figure 5) are placed at the ends of the objective joints at approximately 150 meters from each other on both sides of the structure. The monitoring marks are in number by two at the end of the joint on one side and the other. The total number of landmarks on the viaduct is 40 markers.

Figure 5. Location of the marks on the viaduct

Control points (P1, P2..., P7) (Figure 6) will be determined using GPS technology. The determination of each control point will be done by reading the NAVSTAR-GPS, GLONASS, BeiDou system individually and all together.

Figure 6. Control points

Thus, the accuracy of each constellation will be obtained and we will be able to choose the most accurate position of the point. They will be located outside the viaduct`s area of influence so as to ensure visibility between the network's control points and the station points from which we will read the marks on the objective.

The instrument used to measure the control points is GPS RTK Stonex S10 (Figure 7a, b). The GPS Receiver has a number of 220 channels, can simultaneously receive GPS L1 C / A, L2 E, L2 C, L5, Glonass L1 C / A, L1 P, L2 C / A (Glonass M) SBAS concurrently L1 C / A, L5, Galileo E1, ESA, E5B (reserved) and Bei Dou 2 / Compass: B1, B2.

Figure 7 a) GPS RTK Stonex S10 b) GPS RTK Stonex S10 with accesories

The accuracy of the static horizontal reading is 2.5 mm + 0.1 ppm, static vertical: 3.5 mm + 0.4 ppm, horizontal RTK in fixed solution: 8 mm + 1 ppm, vertical RTK in fixed solution: 15 mm + 1 ppm and DGPS: Horizontal 0.25 m / Vertical 0.45 m.

The station points and monitoring marks will be determined using the modern digital total station Leica TCR 805 Power (Figure 8).

Figure 8. Total Station – Leica TCR 805 Power

The device has a precision of 1" for measuring angles with a 5" accuracy, 1.5 mm precision for distance reading, the maximum sighting distance with prism is 3500 meters and a dual electronic axis for reading compensation.

Along with getting a precise and clearly determined position in real-time of the control points, the station points will have a plain location of known coordinates and improved results will be obtained in the monitoring process of the structure. Thereby, efficiency is achieved on monitoring in time in terms of precision, time, costs and number of operators.

III. Results and discussions

The monitoring in time network of the viaduct consists of the control points P1, P2, ..., P7 determined with GPS RTK Stonex S10 and the monitoring marks R1, R2, ... R40 read with Leica TCR 805 total station by the resection method. The station points on which the equipment was placed were chosen according to the visibility to the marks and to read as many of them as possible in order to optimize the monitoring process in time.

Stationing in each control point (P1, P2,..., P7) I read the positions of the points with the following constellations: GLONASS, NAVSTAR-GPS, BeiDou and all satellites listed simultaneously (Figure 9).

Figure 9. Satellites during measurement process

RTK precision positioning of the monitoring in time network points was achieved using the Network Transport of RTCM via Internet Brăila Protocol (NTRIP Brai_3.1), a permanent GNSS network.

Control point determinations were made by stationing on each point for one minute with a number of 10 readings. The distance between points P1, P2, ..., P7 is located between 30 and 140 meters (Figure 10 a, b).

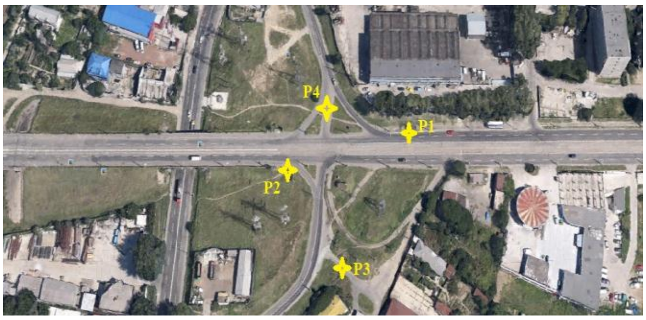

Figure 10. a) Point location P1-P4

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b) Point location P5-P7

Table 1 shows the coordinates of the control points determined with all satellite constellations, as well as the errors on the three directions X, Y and Z on the constellations of the individual satellites NAVSTAR-GPS, GLONASS, Bei Dou.

TABLE 1. DIFFERENCES BETWEEN SIMULTANEOUS AND INDIVIDUAL DETERMINATIONS

Point No.	Coordinates[m]	NAVSTAR-GPS		GLONASS	BeiDou
P1	442301.006	ΔX	1.281	0.016	0.043
	735489.268	ΔY	-0.448	-0.002	-0.011
	45.219	ΔZ	-0.716	0.038	0.114
P2	442280.766	ΔX	0.210	-0.004	-0.024
	735420.742	ΔY	-0.023	-0.005	0.005
	44.784	ΔZ	0.012	0.011	0.031
P3	442230.678	ΔX	-0.003	0.015	-0.001
	735449.661	ΔY	0.030	-0.010	-0.011
	43.269	ΔZ	0.038	-0.022	0.025
P4	442314.226	ΔX	-0.007	0.023	0.016
	735442.889	ΔY	0.025	-0.024	-0.021
	44.320	ΔZ	-0.005	0.011	0.018
P5	442289.462	ΔX	0.069	-0.009	-0.047
	734019.291	ΔY	0.014	-0.035	0.002
	54.712	ΔZ	-0.001	-0.027	0.036
P6	442290.161	ΔX	0.022	-0.026	-0.038
	734140.187	ΔY	0.010	-0.013	0.004
	54.084	ΔZ	-0.026	0.026	0.076
P7	442274.482	ΔX	0.032	-0.022	-0.023
	734160.839	ΔY	0.014	0.001	0.008
	54.241	ΔZ	0.008	0.020	0.023

It can be noticed that the accuracy of NAVSTAR-GPS determinations varies between 0.001-1.280 meters of readings with all constellations. The high values for the three directions for point P1 are due to the location of the point near high trees that obstructed the signal from the satellites. This error can be solved by using the modern digital total station, by reading P1 from other point well determined with GPS tool with resection method. On the other hand, the BeiDou determinations are at a difference of 0.001-0.114 meters from the simultaneous measurements. Also, the time for measuring with BeiDou was very high due to the status of each point, that took long to reach a fixed position. The best accuracy is achieved by the GLONASS constellation, since the differences between the simultaneous and the individual are close: 0.001-0.038 meters.

Differences in the determination of individual and simultaneous satellite constellations occur due to errors influenced by satellite disposition in orbit, atmospheric conditions, satellite visibility, errors in electronic's receiver, instrument's antenna, tropospheric refraction, ionospheric refraction, orthogonal errors and the number of satellites available during reading the point as detailed in Table 2.

TABLE 2. NUMBER OF SATELLITES FOR DETERMINING CONTROL POINTS

Point No.	NAVSTAR-GPS	GLONASS	BeiDou	Simultaneous
P1	8	13	8	14
P2	7	14	9	15
P3	7	14	9	15
P4	7	13	8	13
P5	8	14	7	14
P6	8	15	8	15
P7	8	16	9	17

Table 2 shows the number of satellites with which the control points of the viaduct monitoring network were obtained. One can notice the constellation GLONASS with a large number of satellites and all three simultaneous constellations. This improves the precision of the position of the points, but also the value of the errors decreases.

Factors that must be taken into account when you use GPS technology and may lead to errors are:

1. base length;
2. the number of visible satellites;
3. satellite constellation geometry;
4. signal/noise ratio for satellite signal (Signal to Noise Ratio - SNR) (Lepadatu D. et all., 2014).

Errors that may occur during the measurement process with satellite techniques may be accentuated by GPS receivers through the following parameters shown in Table 3:

1. Position Dilution of Precision – PDOP
2. Horizontal Dilution of Precision – HDOP
3. Vertical Dilution of Precision – VDOP.

TABLE 3. PARAMETERS USED TO ESTIMATE GPS ACCURACY

Point No.	NAVSTAR-GPS		GLONASS	BeiDou	Simultaneous
P1	PDOP	2.0665	1.6283	3.486	1.2064
	HDOP	1.2000	0.9000	1.700	0.7000
	VDOP	1.6824	1.3570	3.043	0.9826
P2	PDOP	2.1558	1.4516	1.4522	1.2207
	HDOP	1.2000	0.8000	0.8000	0.7000
	VDOP	1.7910	1.2112	1.2120	1.0001
P3	PDOP	2.1475	1.4384	1.4472	1.2276
	HDOP	1.2000	0.8000	0.8000	0.7000
	VDOP	1.7810	1.1954	1.2060	1.0085
P4	PDOP	2.0899	1.6225	2.0665	1.4879
	HDOP	1.2000	0.9000	1.2000	0.8000
	VDOP	1.7110	1.3500	1.6824	1.2545
P5	PDOP	1.6954	1.3950	1.7144	1.4994
	HDOP	1.0000	0.7000	1.0200	0.8400
	VDOP	1.3684	1.2065	1.3730	1.2414
P6	PDOP	1.7192	1.2349	1.4917	1.2440
	HDOP	1.0000	0.6400	0.8400	0.6100
	VDOP	1.3984	1.0552	1.2320	1.0839
P7	PDOP	1.7156	1.2007	1.5238	1.1636
	HDOP	1.0000	0.6000	0.8000	0.6000
	VDOP	1.3940	1.0400	1.2954	0.9970

The PDOP values determined with NAVSTAR GPS for points P1, P2, ..., P7 vary between 1-2 meters, which is an excellent efficiency. The same can be said about GLONASS and the values performed with all constellations. Instead, for BeiDou, the PDOP falls between 1-3 meters, indicating a good but not ideal efficiency.

In conclusion, a good accuracy is obtained with the constellation GLONASS, but it is ideal with all satellite constellations due to the excellent PDOP, VDOP and HDOP parameters, but also the large number of satellites received during the measurements and the good visibility between them.

IV. Conclusions

In this scientific paper we have determined the accuracy of control points using the satellite method to monitor the behavior in service stage of a civil engineering structure of viaduct type.

In this context, the measurements were made using a GPS tool using the simultaneous connection of the satellite constellations and the individual choice.

The results showed that in terms of good visibility, unobstructed by climatic conditions, high buildings or trees, the signal received by GPS had better performance, reliability and availability. Following the studies on the values of each type of individual and combined constellations, the positions of the control points were obtained. c

The ideal accuracy for the control points was determined using the GLONASS satellites, but also by the combined use of the constellations available by the receiver used. Thus, an increase in data quality, stability of control points, prevention of signal loss and combined and simultaneous availability of satellites are achieved.

Also, by determining the position of the control points as accurately as possible, Leica TCR 805 total station was set on the points obtained in real-time with the GPS technology, gaining a very good accuracy over the monitoring marks of the objective.

Monitoring the behaviour of buildings in time through modern digital surveying methods implies the achievement of an optimal system in terms of accuracy, time and cost.

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