GNSS TECHNOLOGY APPLICATION FOR THE MONITORING OF FANTANELE DAM, IN COUNTY CLUJ

Dan VELE, şef. lucrări drd.ing. – Faculty of geography,Babes Bolyai University
Ioan STOIAN, şef. lucrări drd.ing. – Faculty of geography,Babes Bolyai University, stoian_ioan2001@yahoo.com

***Abstract**: This paper presents the conclusions of an intent in order to put into practice the GNSS technology for the monitoring of Fantanele dam in county Cluj. Although the monitoring period was very short, some conclusions could be drawn and can be taken into consideration in the future experiments regarding the introduction of this methodology alongside other monitoring means in what hydro-technique constructions behave in time.*

Keywords: *GNSS technology, GPS measurements, dam monitoring*

1. Introduction

The monitoring of save exploitation of the dams has a very special importance also when analyzing the precision of the instruments and methods that are meant to keep track of how the measurement and control apparatus behave.
The evolution of the instruments and measurement systems of the parameters that influence the structural deformations or the dislocations (chaps, joints, leakages etc.) has evolved quite a lot lately. While in the past, the instruments with mechanic or electric functioning with 'in situ' measurement were preferred, at present there are more and more automatic monitoring systems which conduct over the information into collecting, processing and intendment centers.
Unlike the measurements with EMM equipment, the implementation of geodetic methods (figure 1) related to the same requirements are much more accurate measurements executed over long periods of time (cca. 6 months from one era to another), *with high precision* equipment (the tenth of a millimeter can be achieved with the aid of the apparatus and the technology of measurement and modern processing), with extremely high reliability and durability and the measurement range includes all the monitored area, including the stability region, outside the influence area of the dam. *The redundancy* in the case of geodetic measurements is essential.

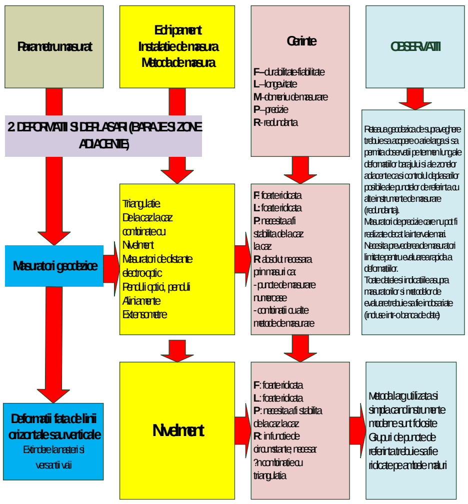

Figure 1. The analysis of the use of the equipment and measuring instruments for the monitoring of hydraulic structures by using geodetic equipment (after Popovici, A)

The emergence of modern methodologies for following-up the behavior of the structures based on sensors or laser technology, modern methods based on remote sensing and on the processing and interpretation of images, could not fully replace the geodetic methods of monitoring the behavior of structures, that still presents remarkable advantages, as follows:

- geodetic methods are the only ones which can reveal the 'absolute' deformations of the strctures
- the precision measurements is superior to other methods
- with the help of these methods one can determine the selective information of the entire construction or of some parts of it (only vertically or horizontally, etc)[20]

If we take into account the developments in both geodetic instruments and the new technology acquisition and processing of the measured data, directly through geodetic methods, one can achieve remarkable results both in the analysis and interpretation of displacements and strain constructions, and especially in the precision with which the strains' amount can be determined in time, from one cycle of measurements to another.
Modern topo-geodetic methods through the high precision measurements and by ways of acquisition, processing and interpretation of data results, represent a very efficient information system in the process of studying the behavior of hydraulic structures (figure 2).

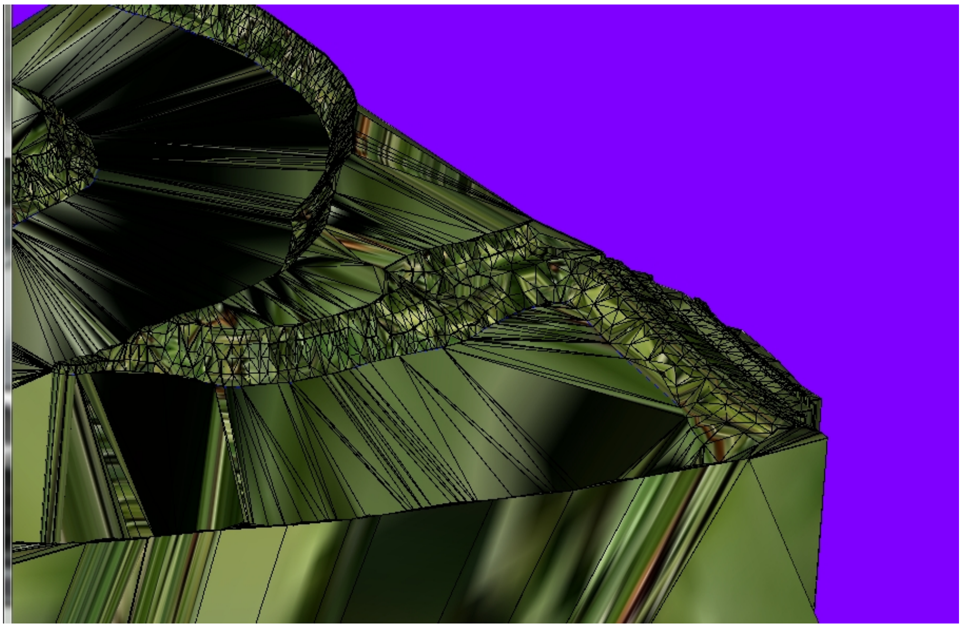

Figure 2. The digital model of Fantanele dam based on geodetic measurements

Both in classical and modern approaches, there is the question of building a geodetic tracking network in a relatively stable area against the applied targets on the construction subjected to the follow up, that can ensure the stability of the points between time intervals in which cyclical measurements were executed.[19]
The first cycle is considered the reference cycle (zero cycle). In this case the projecting and implementation of network configuration had to ensure the measurements accuracy, a system of materialization of geodetic points, their maintenance over time and last but not least, to take into account the fact that a proper analysis of displacements and deformation can be done only if at each measurement period will be considered the same points from the geodetic tracking network.

Geodetic networks are built on the principle of uniformity, by pursuing the accuracy of a uniform determining for all the points of the geodetic tracking network, therefore the availale networks are preferred, that do not allow the introduction of some errors produced a priori.
In a free geodetic network, the volume of the initial data consists of the values of temporary variables, measurements and the corresponding covariance matrix.

In the classic case it was relatively difficult to carry out an exact zoning, the stability of the tracking network was determined by accurate measurement and the homogeneity of the network implied rigorous compensation methods.
With the advent of GNSS tracking network, the coordinates of the tracking network points can be determined through satellite measurements, which if processed correctly (by applying all the necessary corrections), can solve the problem of the stability of the influence zone, the only impediment being the fact that in the cities, the tall buildings can block the optimal visibility of the satellites.[12]

After the completion of the field works the GPS observations were downloaded from the receivers, the calculations of the antennas heights were verified, the land forms of the observations, the constructions' diagrams, the topographical descriptions and the photos of the stationed points.[7]
In the calculation was used the ARP height.

Table no. 1 Shows the Chart of the safety observation sessions which includes the sessions, type, mode and the time when the observations were made.

Nr. Crt.	Ziua GPS	ID punct	Tipul antenei	Modul de măsurare al înălțimii antenei	Start	Durata
1	106	**PI**	JAV TRIUMPH-1	Bottom of antenna mount	16/04/2012 7:55	6:04:10
2	107	**PII**	JAV TRIUMPH-1	Bottom of antenna mount	17/04/2012 7.56	6:01:00
3	107	**PIII**	JAV TRIUMPH-1	Bottom of antenna mount	17/04/2012	6:11:00
4	106	**PIV**	JAV TRIUMPH-1	Bottom of antenna mount	16/04/2012	6:03:10
5	107	**I**	JAV TRIUMPH-1	Bottom of antenna mount	17/04/2012	6:00:40
6	107	**II**	JAV TRIUMPH-1	Bottom of antenna mount	17/04/2012	6:01:20
7	106	**III**	JAV TRIUMPH-1	Bottom of antenna mount	16/04/2012 7.57	6:10:00
8	106	**IV**	JAV TRIUMPH-1	Bottom of antenna mount	16/04/2012	6:08:00

In table no. 2 shows the ellipsoidal coordinates of the permanent stations that went into processing.

Table 2, Dimensional ellipsoid ETRS89 coordinate inventory of permanent stations.

ID punct	Trapez	JD	Denumirea punctului	Cod GPS	Clasă	Coordonate elipsoidale - elipsoid GRS80		
						Bw	Lw	Hw [m]
CAMP	L-34-72-C	CJ	Campeni	CJ-A-0002	A	46°04'39.77004"N	23°33'58.55506"E	307.527
CLUJ	L-34-67-B-a	CJ	Cluj	CJ-A-0001	A	46°45'27.86162"N	23°35'11.52347"E	470.098
BEIU	L-34-45-D-a	BH	Beius	BH-A-0001	A	46°40'09.84637"N	22°21'05.20158"E	244.472
ZALAU	L-34-69-B-a	SJ	Zalau	SL-A-0001	A	46°15'59.31620"N	22°20'16.11551"E	251.687
ORAD	L-34-32-D-d	BH	Oradea	BH-A-0000	A	47°03'33.17025"N	21°56'29.92212"E	197.329

The GPS information processing was performed with Trimble Business Center software v.2.40. For processing, precise ephemeris were used which were accessed on http://igscb.jpl.nasa.gov/.
In the beginning, the vectors of permanent stations were calculated, then the vectors between permanent stations and the new points. At Huedin permanent station there were no obsevatios recorded in the days of 16.04.2013 and 17.04.2013. Therefore, for the comparison of the

ellipsoidal coordinates, one will take into consideration its coordinates from the National Geodetic Fund inventory.[10]
The network points were offset block, the network being constrained on two permanent stations(CAMP şi CLUJ), using network processing and observations from the permanent stations BEIU, ZALAU, Oradea (GPS network sketch).

Table no. 3 Represents the ellipsoidal coordinates and their determination accuracies.

ID	B_w	L_w	H_w [m]	S_X [m]	S_Y [m]	S_Z [m]	Constrângere	Rețea
CAMP	**46°04'39.77004"N**	**23°33'58.55506"E**	**307.527**	**0**	**0**	**0**	**BLh**	**FANTANELE**
CLUJ	**46°45'27.86162"N**	**23°35'11.52347"E**	**470.098**	**0**	**0**	**0.012**	**BL**	**FANTANELE**
BEIU	46°40'09.84637"N	22°21'05.20158"E	244.472	0.00155	0.00131	0.00660		FANTANELE
ZALAU	46°15'59.31620"N	22°20'16.11551"E	251.687	0.00036	0.00028	0.00117		FANTANELE
ORAD	47°03'33.17025"N	21°56'29.92212"E	197.329	0.00037	0.00029	0.00118		FANTANELE
PI	46°40'11.90766"N	23°03'24.95247"E	1045.823	0.00034	0.00027	0.00115		FANTANELE
PII	46°40'08.44527"N	23°03'32.89501"E	985.27	0.00037	0.00029	0.00120		FANTANELE
PIII	46°40'05.16186"N	23°03'33.93331"E	1012.737	0.00033	0.00026	0.00114		FANTANELE
PIV	46°40'04.57737"N	23°03'27.97257"E	1046.057	0.00034	0.00027	0.00115		FANTANELE
I	46°39'57.41638"N	23°03'14.50789"E	1046.522	0.00034	0.00026	0.00114		FANTANELE
II	46°39'52.89276"N	23°03'30.62510"E	1055.299	0.00038	0.00030	0.00120		FANTANELE
III	46°39'56.25545"N	23°03'33.41561"E	1037.341	0.00104	0.00083	0.00460		FANTANELE
IV	46°40'00.66182"N	23°03'15.45421"E	1051.103	0.00155	0.00131	0.000274		FANTANELE

*Staţii permanente pe care s-a contrâns reţeaua

Given the technical norms, the required accuracy for the follow up of specific works is + / -0.1 mm. After the constraining, the two points fall into the necessary tolerance for the network lifting points. The points have a smaller precision, less than + / - 0.5 mm, and the lower rate exceeding + / - 0.1 mm. An overall image of the coordinates and results from processing the GPS observations is found in the tables below. With the aid of the TransDAT program, version 4.01, the ellipsoidal coordinates ETRS89 have been transformed into stereographic coordinates 1970.

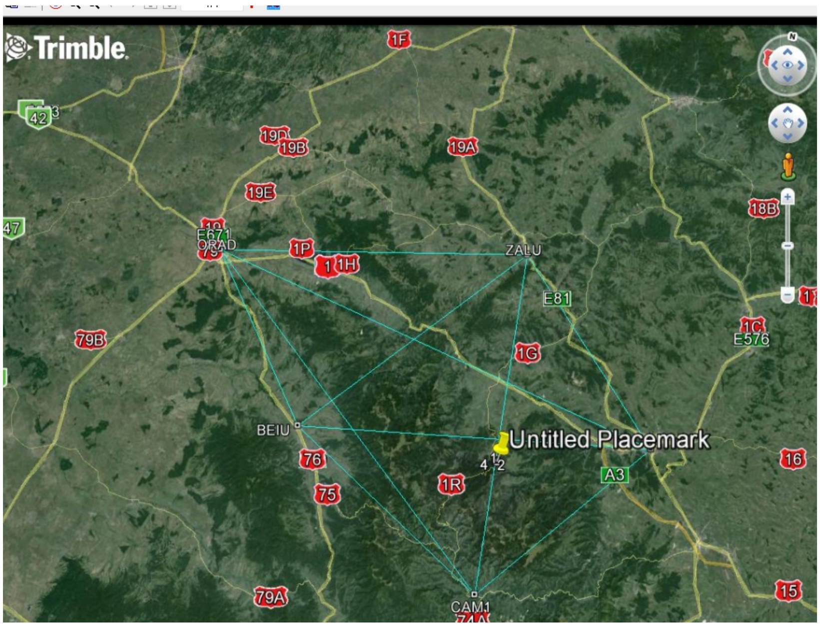

Figure 3. Schematic layout of the permanent stations

An inventory of tridimensional ellipsoid coordinates ETRS89, stereographic 1970 and the 1975 Black Sea odds of GPS points and their determination precision (Tables 4-8).

Table 4 The determination of the coordinates of the points I-IV network tracking system ETRS89

Nr. Pct.	ID punct	Denumirea punctului	Cod unic GPS	Clasă	Coordonate elipsoidale ETRS89 - GRS80			Precizia de determinare			
					B_w	L_w	H_w [m]	S_X [m]	S_Y [m]	S_Z [m]	S_{3D} [m]
1	I	PI-punct retea de observatii	C-JR-0001	R	46°39'57.41638"N	23°03'14.50789"E	1046.522	0.00034	0.00026	0.00114	0.00034
2	II	PII-punct retea de observatii	CJ-R-0001	R	46°39'52.89276"N	23°03'30.62510"E	1055.299	0.00038	0.00030	0.00120	0.00038
3	III	PIII-punct retea de observatii	CJ-R-0001	R	46°39'56.25545"N	23°03'33.41561"E	1037.341	0.00104	0.00083	0.00460	0.00104
4	IV	PIV-punct retea de observatii	C-JR-0001	R	46°40'00.66182"N	23°03'15.45421"E	1051.103	0.00155	0.00131	0,000274	0.00155

Table 5 The determination of the coordinates of the points PI-PI network tracking system ETRS89

Nr. Pct.	ID punct	Denumirea punctului	Cod unic GPS	Clasă	Coordonate elipsoidale ETRS89 - GRS80			Precizia de determinare			
					B_w	L_w	H_w [m]	S_X [m]	S_Y [m]	S_Z [m]	S_{3D} [m]
1	PI	PI-punct retea de observatii	C-JR-0001	R	46°40'11.90766"N	23°03'24.95247"E	1045.823	0.00034	0.00027	0.00115	0.00034
2	PII	PII-punct retea de observatii	CJ-R-0001	R	46°40'08.44527"N	23°03'32.89501"E	985.27	0.00037	0.00029	0.00120	0.00037
3	PIII	PIII-punct retea de observatii	CJ-R-0001	R	46°40'05.16186"N	23°03'33.93331"E	1012.737	0.00033	0.00026	0.00114	0.00033
4	PIV	PIV-punct retea de observatii	C-JR-0001	R	46°40'04.57737"N	23°03'27.97257"E	1046.057	0.00034	0.00027	0.00115	0.00034

Table 6 The determination of the coordinates of the points I-IV network tracking projection system STEREO "70 TRANSDAT program version 4.01 and rates presentation determined by geometric leveling

Nr. Pct.	ID punct	Denumirea punctului	Cod unic GPS	Clasă	Coordonate stereografice 1970 - TransDAT 4.01		Tip nivelment	Cotă MareaNeagră 1975 ed. 1990
					X [m]	Y [m]	h [m]	
5	I	I-punct retea de observatii	C-JR-0001	R	575868.516	351238.011	**geometric**	1003.542
6	II	II-punct retea de observatii	CJ-R-0001	R	575720.478	351577.071	**geometric**	1012.325
7	III	III-punct retea de observatii	CJ-R-0001	R	575822.821	351638.914	**geometric**	994.365
8	IV	IV-punct retea de observatii	C-JR-0001	R	575968.199	351260.582	**geometric**	1008.122

Table 7 The determination of the coordinates of the points P1-PIV tracking network projection system STEREO "70 TRANSDAT program version 4.01 and rates presentation determined by geometric leveling

Nr. Pct.	ID punct	Denumirea punctului	Cod unic GPS	Clasă	Coordonate stereografice 1970 - TransDAT 4.01		Tip nivelment	Cotă MareaNeagră 1975 ed. 1990
					X [m]	Y [m]	h [m]	
1	PI	PI-punct retea de observatii	C-JR-0001	R	576310.369	351470.933	**geometric**	**1002.8680**
2	PII	PII-punct retea de observatii	CJ-R-0001	R	576199.356	351637.076	**geometric**	**942.3131**
3	PIII	PIII-punct retea de observatii	CJ-R-0001	R	576097.466	351656.654	**geometric**	**969.7763**
4	PIV	PIV-punct retea de observatii	C-JR-0001	R	576082.530	351529.553	**geometric**	**1003.0954**

Table 8 The comparison between tranches determined by GPS technology

Pilastru Reper	Coordonate tr "0"		Tranşa apr 2013(zero ptr GPS)		Tranşa mai 2013			
	XN (m)	YE (m)	X_N (m)	YE (m)	X_N (m)	YE (m)	Delta x	Delta y
I	299.9897	449.3614	**575868.516**	**351238.011**	575868.516	351238.011	0	0
II	284.7015	819.7586	**575720.478**	**351577.071**	575720.4726	351577.0753	-5.4	4.3
III	402.4777	840.6915	**575822.821**	**351638.914**	575822.8226	351638.9075	1.6	-6.5
IV	401.1615	434.4731	**575968.199**	**351260.582**	575968.2001	351260.5807	1.1	-1.3
PI	796.3631	507.3803	**576310.369**	**351470.933**	576310.3714	351470.9342	2.4	1.2
PII	753.7017	699.8219	**576199.356**	**351637.076**	576199.3539	351637.0773	-2.1	1.3
PIII	666.3195	755.4734	**576097.466**	**351656.654**	576097.4674	351656.6508	1.4	-3.2
PIV	605.7958	642.5016	**576082.530**	**351529.553**	576082.5424	351529.551	12.4	-2

The global test of congruence in the case when the network configurations are not identical

The global test detects whether there are significant differences between coordinates and, if there are, the next step is the locating of the causative points. Geometric deformation analysis is based on the assumption of identifying the coordinates of the points, the deformed model being called identical or congruent [3](Moldoveanu, Ct., 2002)..

To remove the ambiguity due to processing, as in the previous cases, the global test of congruence is used.

As compared to the previous stage, in the plan of measurement have appeared in the points PV, PS and PD.

In that case, the analysis of displacements-obvious for the common points of the two measurement periods, I divided the information into two blocks corresponding to the common points represented by the subvectorul x_D which consists of reference data- and uncommon points represented by subvectorul x_N

The calculation model is given by :

$$v=[A_1A_2]\begin{bmatrix}x_D\\x_N\end{bmatrix}-l \tag{1}$$

In this case there is provided at least one compensation part , but only for the points that make up the reference data, related to their center of gravity.

It is demonstrated that the sub-matrix Q_{DD}^{+} is pseudo matrix coefficient and normal equation system of points that form part of the reference data.

After compensation, which is made separate on measurements'areas, provided at least in part, for the points that make up the reference data, will result, according to the relations.

$$d_D = (x_D)_1 - (x_D)_2 \tag{3}$$

and

$$(Q_{dd})_D = (Q_{DD}^{+})_1 + (Q_{DD}^{+})_2 \tag{4}$$

In this case R is calculated using:

$$R_D = d_D^T (Q_{DD})_D^{+} d_D \tag{5}$$

If *d* is the fault of the matrix's rank of coefficients and normal stem-degrees of freedom h_D for R_D the corresponding matrix $(Q_{dd})_D^{+}$ is obtained.

$$h_D = n_D - d \tag{6}$$

The calculation of the value and the verification of the null hypothesis is done with the relationships.

$$F_D = R_D / \left(s_0^2 h_D\right) \text{ şi } \quad P_D\left\{F_D > F_{h_{D,f,1-\alpha}} / H_0\right\} = \alpha \tag{7}$$

3. Conclusions

Depending on the chosen method for the analysis of displacements and deformations, it is imposed the making of the compensation of the measured quantities, individually, for each measurement period, or block.
It is necessary the making of the analysis of displacements and deformations by using specific methods on mathematical statistics, because this way one may determine not only some mere differences between planimetric position and the altitude geodetic network tracking points at different measurement periods but their significance is analyzed statistically .
Thus, if these differences contain only information about measurement errors, then they will not be considered as significant, but if the differences contain information on both the measurement errors and the displacements the points have suffered, then these differences will be considered significant.
The building of behavior models of the studied targets, that can provide information about the movements and deformations suffered by the followed objective, the analysis of previous situations, as well as the trends in time, require, as shown by the theoretical treatment, accompanied by practical experiments by comparing between the use of different devices such as traditional and modern methods of classical and modern measurement, including measurement data processing techniques, the application of testing congruence between the ages of measurement.[19]

In this way there can be pointed out the ambiguity and the methods for removing them. More precisely one can find points where displacements occur and one can analyze the cause of these shifts.
A particular conclusion could be drawn regarding the application of GNSS technologies namely the fact that GPS measurements cannot be placed in the overall analysis of measurement periods.
The first GPS measurement is a sort of a reference and the other GPS measurements are related to it.By applying this methodology, it is beneficial because all the geodetic networks tracking points fall in processing, and the mutual visibility between points is not necessary.

References

[1] Bonea, I., Dima, N. Cartografie matematică, întocmirea şi reproducerea hărţilor, Litografia Institutului de mine Petroşani, 1968.
[2] Ghiţău, D. Geodezie şi gravimetrie geodezică. Editura didactică şi pedagogică, Bucureşti, 1983.
[3] Moldoveanu, C. Geodezie, Matrix Rom, Bucureşti, 2002.
[4] Neuner, J. Sisteme de poziţionare Globale, Editura Matrix ROM, 2000.
[5] Palamariu, M. Cartografie şi geodezie,aplicaţii, Editura Rizoprint, Cluj-Napoca, 2004;
[6] Palamariu, M., Pădure, I., Ortelecan, M. Cartografie şi Cartometrie, Editura Aeternitas, Alba Iulia, 2002.
[7] Stoian I, Modernizarea Reţelei Naţionale-Prelucrarea datelor pentru cotarea Staţiilor GPS Permanente, Bucureşti, 2013
[8] Stoian I, Nacu V.-Măsurători geodezice pentru determinarea unui cvasigeoid pentru zona metropolitană Bucureşti, 2012
*[9] * * * Manualul inginerului geodez, Vol. I.II,III, Editura tehnică, Bucureşti 1972-1974.*
[10] P. Iuliu Dragomir, T. Rus, P. Dumitru – Modernizarea Reţelei Naţionale de Staţii GPS Permanente a României , Revista de Geodezie, Cartografie si Cadastru, nr.1 – 2 , 2005.
[11] GPS Reference stations and network, ed Leica Geosystems AG Heerbrugg, 2005.
[12] Grecea C.- Introducere în Geodezia satelitară, Ed. Mirton, Timişoara 1999.
[13] Batty, M., 1997, Virtual Geography. Futures , 29 (4/5), pp. 337–352.
[14] Cartwright, W., Peterson, M., Gartner, G., Eds., 1999, Multimedia Cartography , (Berlin:Springer)
[15] Hillis, K., 2000, Digital sensations: space, identity, and embodiment in virtual reality, (Minneapolis: University of Minnesota).
[16] Longley, P., Goodchild, M., Maguire, D.M. and Rhind, D., Eds., 1999, Geographical Information Systems: Principles, Techniques, Management, and Applications, (New York: J.Wiley and Sons).
[17] McCormick, B., DeFanti, T.A. and Brown, M.D., 1987, Visualisation in Scientific Computing. Computer Graphics, 21 (6).
[18] Vele D, 2013, Măsurători GPS pentru monitorizarea barajului Fântânele
[19]
Vele, D,2012, Rrealizarea unui concept/sistem bazat pe măsurători topografice şi geodezice de urmărire a stabilităţii construcţiilor hidrotehnice-Referat Teza de doctorat
[20] Vele, D., 2013, Analiza sub aspectul eficienţei şi calităţii a metodelor de monitorizare a siguranţei barajelor -Referat Teza de doctorat