CURRENT TRENDS ON MONITORING THE DEFORMATIONS OF STUDIED CONSTRUCTIONS

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***Abstract**: Measurement and data processing technique and technology has been greatly expanded in recent years, coming today to real-time monitoring of the deformations occurred in constructions subject to the tracking process by geodesic methods of in situ behavior. Due to the complexity of in time behavior tracking process of lately raised large buildings and constructions with special character, in addition to known conventional devices and tracking methods, various modern technologies have emerged for tracking and monitoring the in situ behavior of constructions, such as GNSS technology, total automatic and robotic stations, terrestrial 3D laser scanners, inclination sensors etc., the paper presenting some aspects related to these technologies.*

***Keywords**: deformation monitoring, in situ behavior of constructions, Leica GeoMoS, GNSS technology.*

1. Introduction

The activity of monitoring the *in situ* behavior of constructions, which implies a corresponding endowment with specialized equipment and software, is regulated in Romania by *Law No. 10 / 1995, regarding quality in constructions*, amended by *Law No. 123 / 2007*, which specifies that „tracking the behavior of constructions in operation is made throughout their living duration". It is also regulated by the *P 130-1999 Norm regarding behaviour in time of constructions* and *GE-032-97 Norm regarding execution of maintenance and repairs to buildings and special constructions*.

Under the existing legislation, monitoring the behavior of constructions in operation is made by current and by special tracking - which also includes the tracking of behavior by topo-geodetic methods. Tracking the behavior in time of massive constructions (dams, locks, viaducts, etc.), exploited under special environmental conditions, takes place throughout the construction operation time. The constructions operated under normal conditions, without special risks, such as the civil, industrial, agricultural ones, works of art etc., are tracked for a shorter period of time, three to four years, until the deformations and displacements appear to have faded away and the construction stabilizes. In time, if evolutive phenomena affecting the construction occur, it is necessary to resume the measurements, to establish the causes and to perform rehabilitation/ consolidation works, maintenance works included.

The term *behavior in situ of constructions* defines the manifestation way of physical and chemical changes they undergo during the process of interaction with the (natural and technological) environment and with themselves. The latin phrase *in situ,* means *on the place of occurrence and existence,* respectively *on site* [1].

Tracking the *in situ* behavior of constructions envisages to detect mismatches between expectations / provisions and reality, in order to prevent and avoid any risk of losing the qualities that define the operational capability of the studied constructions. Subject to tracking are both physical appearance (settling, cracking, corrosion, humidity etc., i.e. the degradation / failure status) and the operational one (incident, accident, damage etc.).

To prevent damage to buildings and to restore their ability for operation in an emergency, a careful monitoring is required, i.e. a systematic tracking of the technical condition and the performance development, accompanied by interventions of maintenance or of rehabilitation of the ability for operating.

Improvement of geodetic instruments and equipment, of methods and technologies for measurement and automated data processing, has created new possibilities for their use in the study of constructions at all stages of implementation, as well operating. Tracking the *in situ* behavior of constructions by topo-geodetic methods provide highly accurate measurements and indicates the absolute size of any displacements and deformations which occur in time. One can say that they are key components in vast process of experimental research, implementation, operation, maintenance and curative maintenance.

2. Current Trends

The company Leica Geosystems has created a software specialized in automatic monitoring of deformations, called ***Leica GeoMoS***, the suggested system being a very flexible and customizable one, able to combine geodetic instruments (total stations, GPS's and GNSS sensors) with geotechnical and meteorological sensors (of temperature and pressure) which can be used to monitor deformation of dams, tunnels, bridges, tall buildings, as well as monitoring landslides.

GeoMoS Leica software includes an ***online application - Monitor***, responsible for checking the sensors, data collection, from sensors included, and by calculating the data received, functioning as a system of management of the occuring events, i.e. taking over the information, and processing it and sending it almost in real time, as well an ***offline application – Analyzer***, responsible for viewing, analysis and data postprocessing. Besides the two main applications, the GeoMoS Leica software also includes an ***adjustment application - Adjustmen***, which gives the user both the possibilities of simulation in the tracking network as well the possibility to make decisions based on statistical optimization and data validation.

The Leica Geosystems monitoring system contains various monitoring equipment and the client can choose the best equipment and methods for monitoring deformations as it follows:

- **Leica GeoMoS** – very flexible software for automatic monitoring of deformations.
- **Leica GeoMoS Web** – is a web-based service, for viewing and analysis of data received from a GeoMoS monitoring system.
- **Leica GeoMoS Adjustment** – possibility of making decisions based on statistical optimization and data validation.
- **Leica TM30** – total automatic and motorized station, robust, reliable, fast and silent, with which one can make high precision measurements. Is able to measure continuously for a long time, even in hostile environments while providing the fastest workflow of the overall measurement process.
- **System 2000** – total automatic stations (TCA 1800, TCA 2003), high performance, robust, which can be used to continuously monitor the deformations.
- **Leica TCA 1201M** – allows remote monitoring of up to 8000 m with a single prism, having a high precision.
- **Leica NIVEL210/220** – inclination sensor for simultaneous measurement of inclination, of the inclination direction and of temperature.

- **Leica GMX902 GG** – GPS GLONASS receiver (**Glo**bal **Na**vigation **S**atellite **S**ystem) high-precision, dual frequency, specially developed to monitor sensitive structures such as bridges, tall buildings, landslides etc..
- **Leica GMX901** – smart GPS antenna, high precision, single frequency, compact, robust and accurate, which can be used for monitoring the sensitive structures listed above, but also dams; is an ideal sensor for deformation monitoring.
- **Leica CrossCheck** – is a web-based service, for deformation monitoring by GPS / GNSS, monitoring which is performed almost in real time.
- **ATHENA Program** – GNSS (**G**lobal **N**avigation **S**atellite **S**ystems) monitoring technologies for academic institutions and research centers.

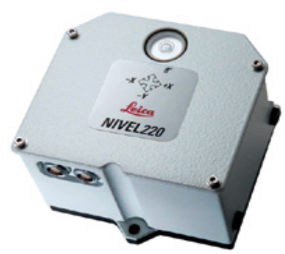
Figure 1 shows the possible equipment of Leica Geosystems monitoring system, and Figure 2 shows various aspects of the monitoring process.

TCA 2003

TCA 1201M

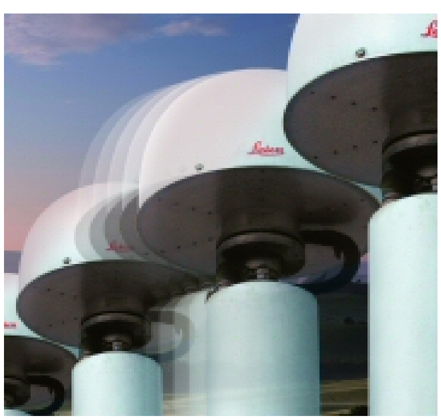
TM 30

GMX 902 GG

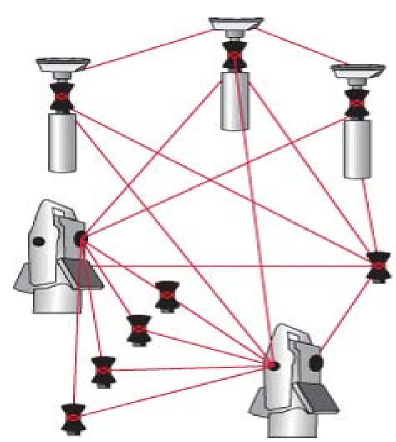


NIVEL 220

GMX 901



Leica CrossCheck



GeoMoS Adjustment Multi Sensor

Fig. 1. Leica Geosystems equipment for deformation monitoring

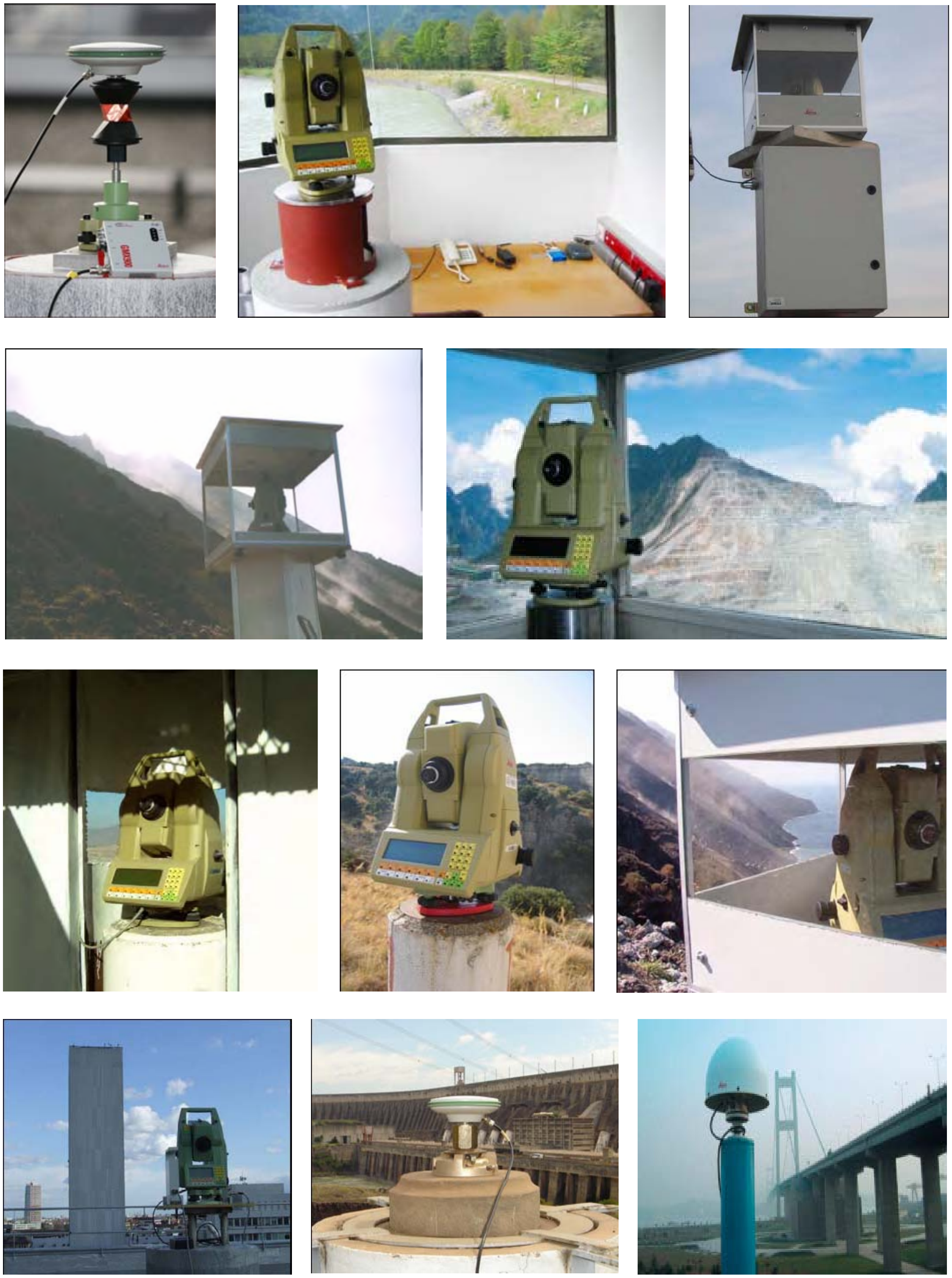


Fig. 2. Aspects of deformation monitoring

The synthetic scheme of a Leica Geosystems monitoring system [8] is shown in Figure 3.

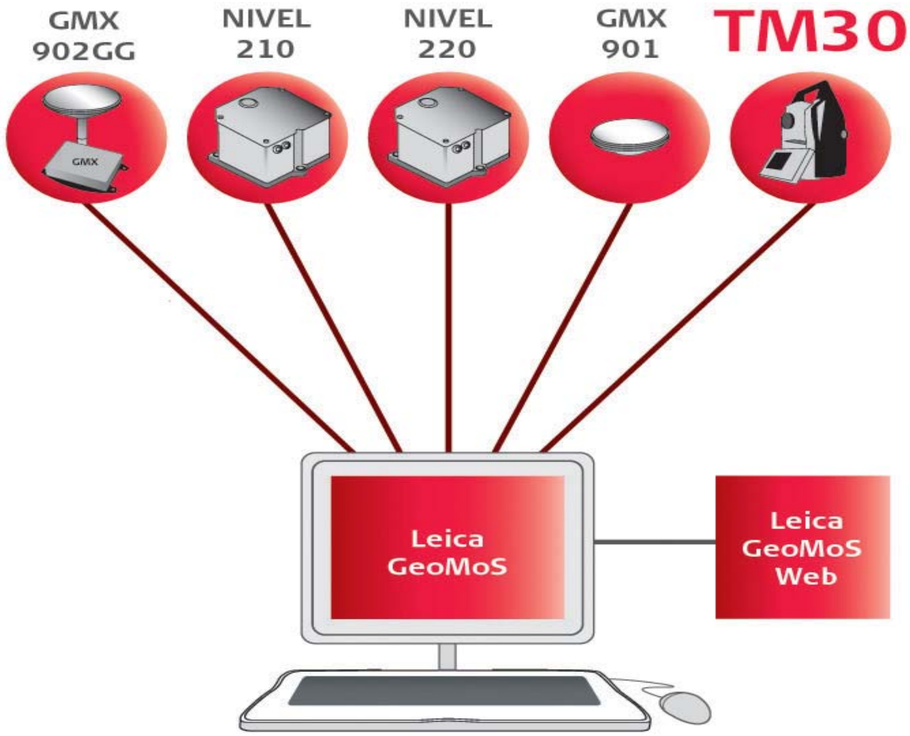


Fig. 3. Leica Geosystems deformation monitoring system

The Leica TS 30 total station of the latest generation provides unlimited flexibility and full compatibility with Leica Systems 1200 [8], which is illustrated in Figure 4:

Fig. 4. Compatibility of TS 30 total station with Leica Systems 1200

The Leica Geosystems total stations that can be used to monitor deformations are: Leica TM 30, TS 30, TPS 1100, TPS 1200, TPS 1200 Plus, TCA 1201 M, TPS 1800 and TCA 2003.

Between GNSS sensors is mentioned: Leica GPS System 500 GPS System 1200, GMX 900, as well as the possibility of connection to Leica GNSS Spider for monitoring through advanced GNSS technologies.

Leica Geosystems has developed specifically for the engineering topography segment, total performing stations, included in the System 2000 (TCA 1800, TCA 2003, TC 2003) project and laser stations designed exclusively for industrial use (TDRA 6000, TDM 5005, TDA 5005). Leica company also designed both the ATR (**A**utomatic **T**arget **R**ecognition) system, various types of prisms, the 360˚ type prisms being particularly useful in measurements made for the continuous monitoring of deformations, as well as the RCS (**R**emote **C**ontrol **S**ystem) system, which can be connected to the total station via an integrated radio modem, so that it can be just as easy measured at the target (prism) and at the instrument itself. Display and keypad on the remote control are fully compatible with the total station, all functions and programs can be accessed by remote control, the operation being identical to the direct use of total station menu.

By means of the Leica GPS - RTK technology, deformation monitoring can be done under any weather conditions, the monitoring system equipment developed by Leica Geosystems being specially designed for use in hostile environment and to resist for a long time. Most total stations of the latest generation, particularly those for industrial measurement and monitoring systems, are provided with the so-called **ATR**'s, which enable automatic target recognition and tracking with high accuracy, even in a group of different prisms. The fact that at present are total performance automatic and / or robotic stations, while recently the GPS technology has also experienced fantastic progress as far as the determining accuracy is concerned, in conjunction with the development of tilt sensors, geotechnical and meteorological sensors, allow for those concerned to turn to specialized companies that currently offer full equipment for the continuous tracking and monitoring of deformations in real time. The GPS's can be equipped with built-in modem, so that, through an optic fiber network, the information collected by the monitoring equipment, which is also stored in their internal memory, will be transmitted via Internet to processing and data analysis centers.

A very important role in the vast process of deformation monitoring is held by the optimal choice of the tracking network for the constructions behavior in time, of the measurement method, the applied instruments, as well as the rigorous processing of observations.

For very remote monitoring, Leica Geosystems developed the total station **TCA 1201 M**, which can measure distances up to 8000 m with a single prism with high accuracy. Because the ATR system and that this type of device is fully automated, it will be able to function as a permanent monitoring station, controlled by the **Leica GeoMoS** software.

Table 1 presents some of the best recent tools that can be used in geodetic, planimetric, leveling, in time tracking and monitoring measurements.

Table 1. Latest generation geodetic instruments

No.	Manufacturing company	Instrument	Determination of accuracy		The instrument type / Observations
			For angles (")	For distances (mm)	
1	Leica	TS 30	0.5	±0.6+1ppm	Total Station / ATR
2	Leica	TM 30	0.5	±0.6+1ppm	Total Station / Sensor monitoring
3	Leica	TCA 2003	0.5	±1+1ppm	Total Station / System 2000
4	Leica	TCA 1800	1.0	±1+2ppm	Total Station / System 2000
5	Leica	TS 09	1.0	±1+1.5ppm	Total Station / Leica FlexLine
6	Leica	TCA 1201M	1.0	±2+2ppm	Total Station / Measure distances up to 8 km with a single prism
7	Leica	TPS 1201 +	1.0	±1+1.5ppm	Total Station / Measure distances up to 1 km without reflector
8	Leica	TDRA 6000	0.5	±0.3+13μm/m	Laser Station / Industrial
9	Leica	TDM 5005	0.5	±0.3+1ppm	Laser Station / Industrial
10	Leica	TDA 5005	0.5	±0.3+1ppm	Laser Station / Industrial
11	Leica	TM 5100A	0.5	±1+2ppm	Industrial Theodolite / Motorized
12	Sokkia	NET 1	1.0	±1+1ppm x D	3D Total Station / Automated
13	Sokkia	NET 05	0.5	±0.5+1ppm x D	3D Total Station / Automated
14	Trimble	S8	1.0	±1+1ppm	Total Station / Robotic
15	Leica	DNA 03	±0.3mm / 1km d.n.		Digital Level / Invar staff
16	Leica	DNA 10	±0.9mm / 1km d.n.		Digital Level / Invar staff
17	Leica	NA 2; NAK 2	±0.3mm / 1km d.n.		Optical level / Invar staff
18	Sokkia	SDL 30	±0.6mm / 1km d.n.		Digital Level / Invar staff
19	Sokkia	B1; B1 C	±0.5mm / 1km d.n.		Optical level / Invar staff
20	Topcon	DL-101C	±0.4mm / 1km d.n.		Digital Level / Invar staff
21	Topcon	AT-G1; AT-G2	±0.4mm / 1km d.n.		Optical level / Invar staff
22	Trimble	DiNi	±0.3mm / 1km d.n.		Digital Level / Invar staff
23	Nikon	AS-2; AS-2C	±0.4mm / 1km d.n.		Optical level / Invar staff
24	Nikon	AE-7; AE-7C	±0.45mm / 1km d.n.		Optical level / Invar staff
ATR – **A**utomatic **T**arget **R**ecognition					

3D Terrestrial Laser Scanners can reach a scanning accuracy up to 3mm, so that they can be successfully used to track the behavior of certain constructions, where the required precision is not very high and the ground situation allows for their use; they have the disadvantage that the scanned image acquisition should be done from the smallest distance possible from the building - to achieve the highest accuracy of determination, which means that the land around the building is stable in time.

Using **T**errestrial **L**aser **S**canners (**TLS**), although it is a more recent technology, proves to be promising for the near future, in the vast process of determining and monitoring deformations of constructions under investigation. Although the first **TLS** were marketed over a decade ago, currently there is still no ISO standard to regulate the field testing procedures of such devices. The operation of field testing and calibration of laser scanners is particularly important because it has been that demonstrated that **TLS** are still affected by instrumental errors, which can be reduced by instrument calibration. It is necessary, therefore, that in the shortest time to adopt a calibration standard of this instrument, namely **ISO 17123, Part IX - Terrestrial Laser Scanners**, which is currently under development.

Figure 5 shows the best terrestrial laser scanners manufactured by various companies, specialized in producing topo-geodetic equipment.

Fig. 5. Terrestrial Laser Scanners

Laser scanners work almost similarly with reflectorless total stations, their calibration being mandatory; *auto calibration represents determination of all systematic errors of a terrestrial laser scanner, simultaneously with all the parameters of another system* [5]. The georeferenced process of **TLS** is one of the most important steps in processing the data obtained by scanning with this device, which presupposes transformation of the data with *clouds – point character* into a *real world* i.e. a space system of coordinates, necessary to integrate the data obtained by using **TLS** with other geospace data. Virtually, it is required as a necessity to establish or know the scanner position and orientation during the study, which can be done in a manner similar to routine work of total stations. Thus, the scanner may be stationed on a point of known coordinates and oriented on another known point, the data resulting from the scan being obtained in a real coordinate system, increasing efficiency and reducing costs and working time. Determining the scanner position and orientation of the against a reference system can be done by using the GPS technology. A further advantage of using **TLS** technology in addition to the relatively high precision which can be achieved, the shorter time for measurements and their low cost, the ability to measure very many points in the area subjected to research and not just in the control points, is that together with the deformation determination and monitoring to which the constructions are subjected, a number of quality images of the building and its surrounding area are taken and recorded, images that at times can be very helpful.

Table 2 lists the main features of the best terrestrial laser scanners [2], which can be used to track the behavior in time, where the accuracy of determining the deformation vector is not very high.

Table 2. Characteristics of terrestrial laser scanners

Scanner / Criterion		Trimble GX	Leica ScanStation 1	Leica ScanStation 2	Riegl LMS-Z420i	FARO LS 880 HE	Z+F IMAGER 5006
Field of view [°]		360 x 60	360 x 270	360 x 270	360 x 80	360 x 320	360 x 310
Scan distance [m]		350	300	300	1000	< 76	< 79
Scanning speed [pts/sec]		≤ 5000	≤ 4000	≤ 50000	≤ 11000	120000	≤ 500000
Angular resolution [°]	**V**	0,0018	0,0023	0,0023	0,0020	0,00900	0,0018
	H	0,0018	0,0023	0,0023	0,0025	0,00076	0,0018
3D scan precision		12mm/100m	6mm/50m	6mm/50m	10mm/50m	3mm/25m	10mm/50m
Camera		integrated	integrated	integrated	add-on option	add-on option	add-on option
Inclination sensor		compensator	compensator	compensator	compensator	yes	yes

Thus, as a result of technology development and computing technique in recent years, various targets that require tracking the *in situ* behavior were endowed and monitored with modern equipment and techniques. Of them itself mention *the Hoover Dam in the U.S.A.*, which is monitored ever since the year 2000 by using the GPS Trimble 4800 technology, the GTS 312 total stations, the Riegl LMS - Z 210 3D laser scanners made in the U.S.A., as well as the monitoring of the *London Millennium Bridge*, by using the Leica company technology, i.e. GPS's SR 510, TCA 2003 total stations, motion sensors and Cyrax 2500 laser scanners etc..

3. Conclusions

Measurement and data processing technology has grown very much in recent years, to arrive to real-time monitoring of deformations, an extraordinary fact, allowing to take urgent action in extreme cases, such as remedying of occuring defects or warning and rapid evacuation of the population in case of an earthquake of high or very high intensity, avoiding thus the danger of a disaster occurrence.

Unfolding the activity of tracking the *in situ* behavior of constructions, run by specialistls with a very good professional, scientific and technical training, requires an exemplary organization in every respect, as well as the use of measuring equipment and methods to ensure the accuracy required by such works. Knowing how constructions behave in time is particularly important, enabling the possibility of a fair assessment of the suitability for service of such constructions.

Today, thanks to the peak technique and technology which has been reached, the *in situ* surveillance of constructions can be virtually performed in real time or online, the system thus created being called **deformation monitoring manager system**; surveillance include two distinct but interrelated activities by their common goal: ensuring the safe operation and suitability for interventions that are necessary to be carried out on the constructions.

The State authorities are imperiously required to quickly engage in the implementation of complete equipment or systems for the monitoring of real time deformations, at first at least at very large dams, with a catastrophic impact in the event of serious damage.

4. References

1. *Hann F. E. I. – Comentarii privind reglementările româneşti referitoare la urmărirea comportării in situ a construcţiilor. Colecţia "Comentarii şi recomandări CNCisC", Comisia Naţională Comportarea in situ a Construcţiilor – CNCisC, Bucureşti, 2004;*
2. *Kersten T. P., Mechelke K., s.a. – Geometric Accuracy Investigations of the Latest Terrestrial Laser Scanning Systems, FIG Working Week, 14 – 19 June, Stockholm, Sweden, 2008;*
3. *Nistor Gh. – Geodezie aplicată la studiul construcţiilor, Ed. Gheorghe Asachi, Iaşi, 1993;*
4. *Onu Cr. – Contribuţii privind folosirea metodelor topo-geodezice la urmărirea comportării in situ a construcţiilor, Teză de doctorat, Iaşi, 2009;*
5. *Reshetyuk Y. – Self-calibration and direct georeferencing in terrestrial laser scanning, Royal Institute of Technology, Printed by Universitetsservice US AB, Stockholm, Sweden, 2009;*
6. *http:// www.faro.com;*
7. *http://www.lasertech.com;*
8. *http://www.leica-geosystems.com;*
9. *http://www.nikon-trimble.com;*
10. *http://www.riegl.com;*
11. *http://www.sokkia.com;*
12. *http://www.topcon.com;*
13. *http://www.trimble.com;*
14. *http://www.zf-laser.com.*