Geometric Structural Monitoring in Cinematic Regime- dynamic Surveying as Means to Assure a Structure Safety

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Key words: performed structures, Dynamic Surveying, very tall building, Verticality.

SUMMARY

Construction safety cannot be conceived except by assuring a careful geometric monitoring in static, cvasistatic or cinematic regime of the execution and time behavior of the performed structures.In the study of some phenomena that escaped the methodological control of only one research area, the interdisciplinary approach proved to be very useful, sometimes even indispensable. The complex character of elastic interactions between external influence – construction structure entails an interdisciplinary vision that implies many activity areas: special structures – surveying – metrology – meteorology – electro-techniques – electronics – physics, etc, thus contouring a new chapter of surveying, which could be called Dynamic Surveying.

The purpose of the paper is to present this new chapter of surveying and its role in structure safety.

The research subject initiated 30 years ago, in which the new concept has appeared and developed, is called "Dynamic Surveying", and for very tall buildings „Verticality".

The main results were:

1. Defining the Dynamic Surveying components and thus creating the platform for developing the new concept.
2. Identifying the danger that some cumulated forces on cumulated underprivileged action grid represent for structures safety.
3. Illustrating the concept of manager system in coordinating the geometry of executing the structures under stress.

The conclusions of the paper will emphasize the fact that Dynamic Surveying, though it has a very strong interdisciplinary character, is a developing of classic surveying methods in the cinematic space and therefore should be considered as a distinct and separate chapter.

The safety of the inhabitants of a very tall building, of the people that use a very long bridge, cannot be accomplished except by the existence of safe structures, the role of Dynamic Surveying being definitive.

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1. INTRODUCTION

All structures, are designed to support certain loads without deforming excessively. Long bridges, dams, chimneys, TV towers, very tall buildings are subject to catastrophic collapse. The principals causes of building collapse can be classified under general headings to facilitate analysis. These headings are: Bad Design, Faulty Construction, Foundation Failure. Extraordinary Loads , Unexpected failure modes, Combination of causes.
In stage of design, consider that it is necessary to approach cautiously about the possibilities to combination of causes, coupling of stress factors. To know the general, particular and special model behavior of the building A, with parameters B, emplaced in zone C, characterized by the environmental factors D, make possible to estimate the unfavorable possibilities to coupling of forces.
Construction safety cannot be conceived except by assuring a careful geometric monitoring in static, cvasistatic or cinematic regime of the execution and time behavior of the performed structures. This is how new methods appeared for assuring the geometry, taking into account the perturbing factors – the main one being the action of the wind. Situated at the border between structures safety – meteorology – surveying, the new domain is therefore an interdisciplinary one. There should be identified an axis by which this should be defined and developed.

2. OUTLINING THE OBJECT OF STUDY OF DYNAMIC SURVEYING

Recreating the optimal design cycle of special reinforced concrete and metal structures in a certain space: in-situ behavior under the action of some stresses variable in time (wind, temperature, exploitation), implies monitoring them in dynamic regime (figure 1).
Among the applications of Surveying in the field of special structures (figure 2), the "dynamic" part refers to the study, recording and processing of characteristic parameters of external influences, as well as of the geometry of structures, under the action of some variations of some stresses in a short period of time (at most 24 hours). For special structures, the "behavior at temperature variations" lies within dynamic analysis, implying a diurnal variation of the geometry, therefore measurable parameters using classical means. Also the "behavior under the action of wind" or under load lies within dynamic analysis, generating a variation of the geometry, with optimal data collecting periods between 0.01-1 s. In this case, the classical operating means of Surveying are not operable.

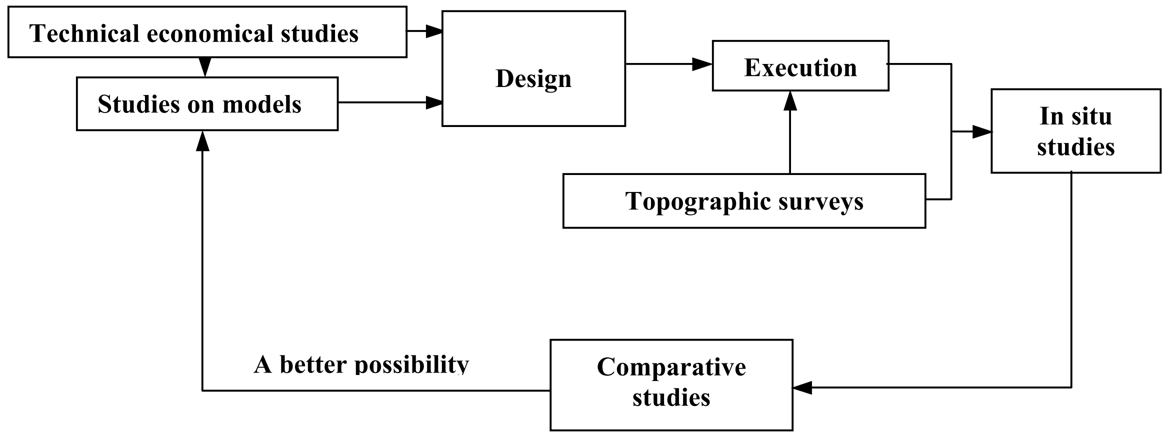

Figure 1

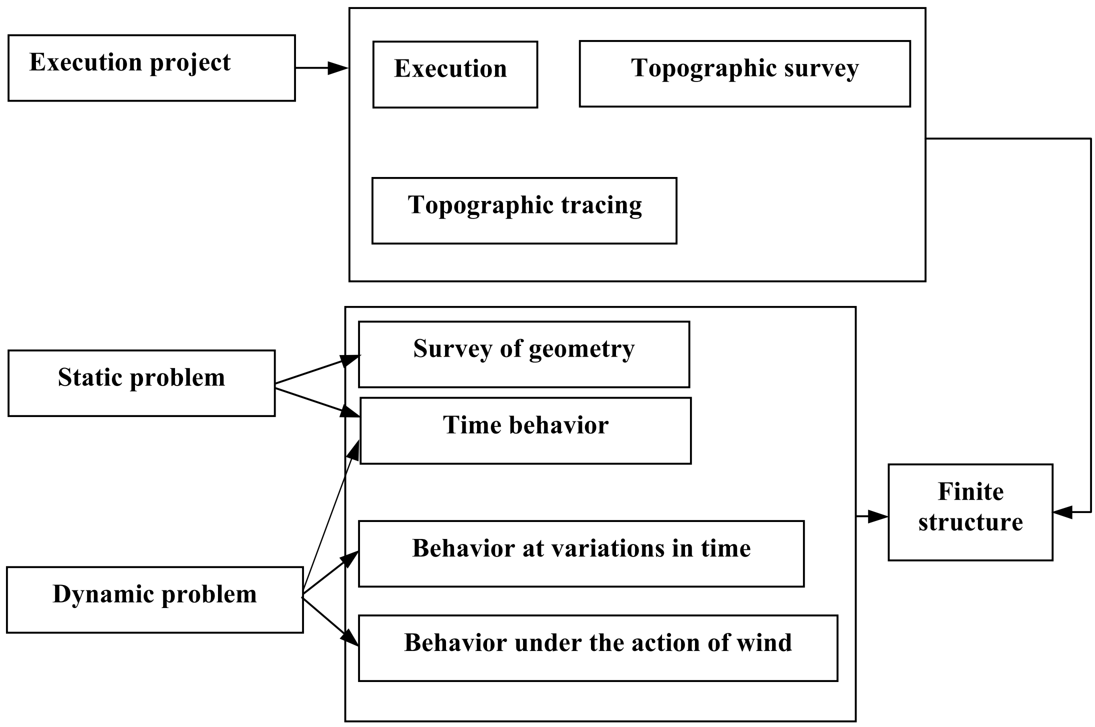

Figure 2

3. STRUCTURES IN DYNAMIC REGIME

The stresses that operate on construction structures have a continuous character, when the inertia forces have sizes comparable to the intensity of the action that generates the phenomenon. Thus, the action of some equipment and industrial devices, earthquakes, temperature variations, wind lead to the production of some dynamic behavior phenomena, described by equations of the following form:

$$\Delta d = Df \qquad (1)$$

where:

- Δd – the main unknown of the problem – usually a displacement system, subjected to some limit constraints;
- D – system of mathematical operations;
- f – the constant term, corresponding to the action taken into consideration, which could contain the initial conditions, too.

3. METROLOGICAL OUTLINING

Studying the variation of some geometric variables (ΔX_i, ΔY_i) or (D_i, θ_i) depending on time and on the parameters of the stress (direction, orientation, speed) implies the methodological approach of the phenomenon. Thus, the metrology of geometric variables, of time, the characteristics of the environment intervene directly, and the metrology of electrical variables intervenes indirectly. Taking into account the double mission of metrology: **to pretend** some performance from the producer of measuring devices, and **to ensure** the user (beneficiary) of this performance, in this case, the following question rises:
"We shall start with the method, going towards the devices, or, having a series of instruments, we shall adopt the methods?".
Methodologically, the inter-relations will be studied from figure 3.
The connections ® and © are determined by the two possibilities of recording the dynamic parameters:

1) without having direct contact with the structure; and

2) the instruments are assembled directly on the structure.

The models of topographic survey (theodolite, Total station), photogrammetric survey, registered on film or video belong to the first category. In the second category there are included the unconventional methods, methods for monitoring the structures, instruments and techniques that have to be included in the sphere of Surveying(Dynamic surveying). The basic condition of recording is taken into account: ensuring the uniformity of measurements in what concerns the accepted precision.

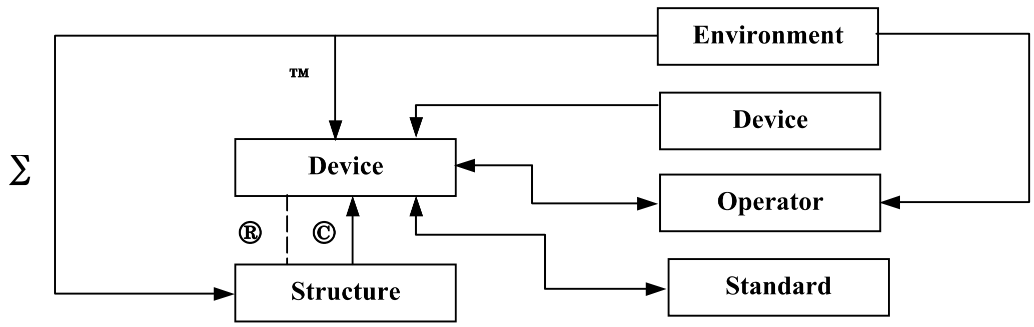

Figure 3

In this case, the metrological principle "no measure is perfectly constant in time" is especially real, for it needs to place the measurement information into the specified category (figure 4).

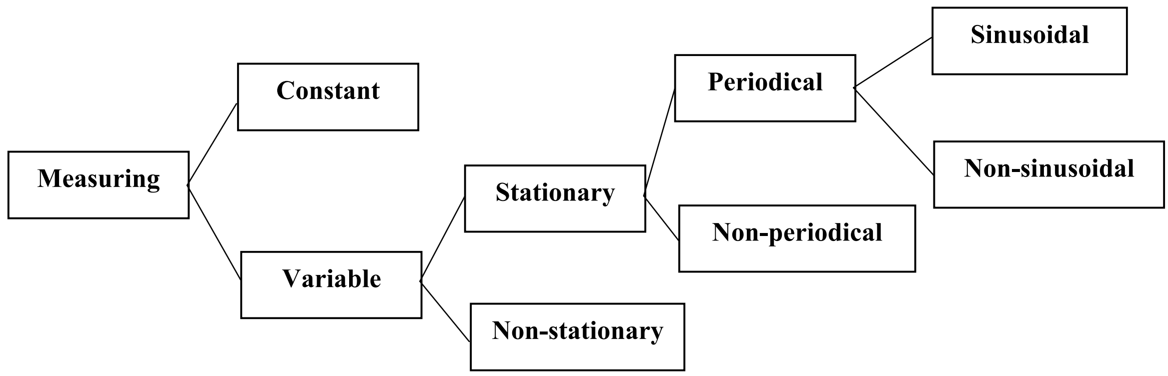

Figure 4

In this case, there will be measured the functions $x(t)$, $y(t)$ of the variables x, y, depending on the time t. In the case of measuring "through points", series of the measured variables will be obtained, which form the flow of information Q:

$$Q = n \times I \tag{2}$$

where:

n – is the number of pieces of information per time unit ;
I – the primary information.

It can be reached to n = 30 inf/min, I being of geometric nature: angle or distance, one of each piece of information. Establishing the equation of the exit variables (figure 5), these will have the general form (3):

$$y_i = (x_i, \dots, x_n; v_1, \dots, v_p; c_1, \dots, c_q) \tag{3}$$

where:
y_i – exit variables;
x_i – measured variables;

v_i – influence variables;
c_i – device instructions.

$$\Delta y_i = \frac{\theta f_i}{\theta x_i}\Delta x_i + \frac{\theta f_i}{\theta v_1}\Delta v_1 + \dots + \frac{\theta f_p}{\theta v_p}\Delta v_p,\quad i = 1, \dots, m \qquad (4)$$

where: $\frac{\theta f_i}{\theta x_i}$ represent the useful sensibilities of the measuring device, and must have exact values, as stable in time as possible, resulting the device errors, and $\frac{\theta f_i}{\theta v_p}$ represent the parasitic sensibilities of the measuring device, determined and situated under certain limits, as possible. The exit variables can be addressed to the operator or to a processing and recording technical system.

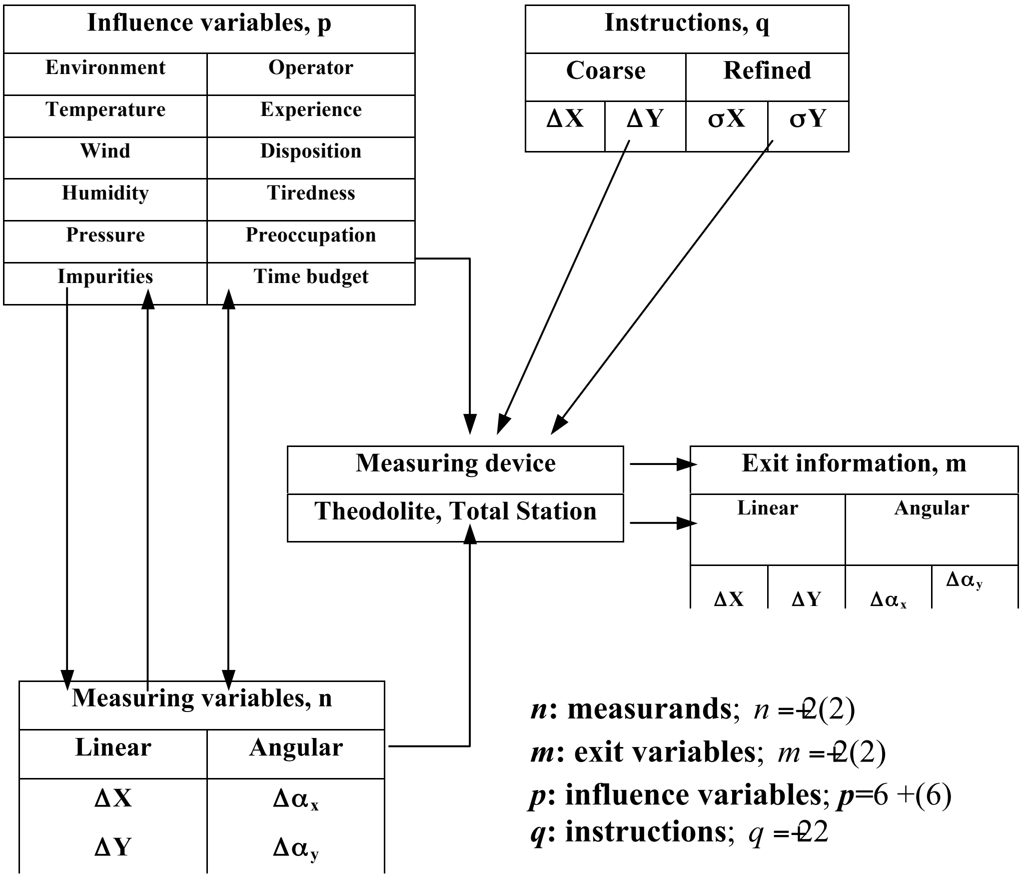

Figure 5

When choosing measuring devices, there should be taken into account the needed precision, the existing perturbations, the necessary measuring speed, the length of a measurement, the environmental and location conditions, the simplicity, the volume, and the cost. Of course, here such a measuring system is referred, which allows measuring a series of variables based on a “software” measuring program. The offer of methods is now very large, there existing real manager systems for monitoring the behavior of structures under the action of some dynamic stresses. In the case of measurements variable in time (dynamically stressed structures), there appears the notion of dynamic error. Concretely, in dynamic regime, the exit variable does not respect completely the variation of the input variable. Among the causes there are: the inertia of the mechanical parts of the device, the reactive components from the circuits of its electrical part. In the end, the data should be presented separately, but also cumulated, because an unfavorable superposition of the effects can lead to the production of a discontinuity in the behavior of the structure (mathematically called catastrophe), though each cause is situated within design limits.

Table 1

Nature of the variable	Geometric	Distances	ΔX
			ΔY
		Angles	$\Delta \alpha_X$
			$\Delta \alpha_Y$
	Atmospheric	Wind	Direction, orientation, speed (at various levels)
		Temperature	Exposed wall, shadowed wall
Interval of measurable values	Geometric	Distances	min. 0,1 mm, max. 2 mm
		Angles	min. $0{,}1^{cc}$, max. 10^{cc}
	Atmospheric	Wind	Direction ± 1^0, speed min. 0,1 m/s; max. 5 m/s
		Temperature	min. 1^0 C; max. 5^0 C
Time variation	Geometric	Constant variables	Distance device – structure
		Periodically-variable variables	ΔX , ΔY ; $\Delta \alpha_X$, $\Delta \alpha_Y$
		Non-periodically-variable variables	ΔX , ΔY ; $\Delta \alpha_X$, $\Delta \alpha_Y$
	Atmospheric	Constant variables	$\approx TC^0$ for single cycles at the action of wind
		Periodically- variables	$VȚC^0$
		Non-periodically- variables	$VȚC^0$

4. THE INTERDISCIPLINARY PROGRAM, NAMED “VERTICALITY”

Behavior models for climatic factors influence and the vertical axis evolution of tall buildings especially on top may form benchmarks for design methods reappraisal in this kind of works. In this domain is extremely important to know environment indicators and the emplacement zone. Further researches, are situated in a more ample interdisciplinary program, named “Verticality”, of the main direction are showed in figure 6.

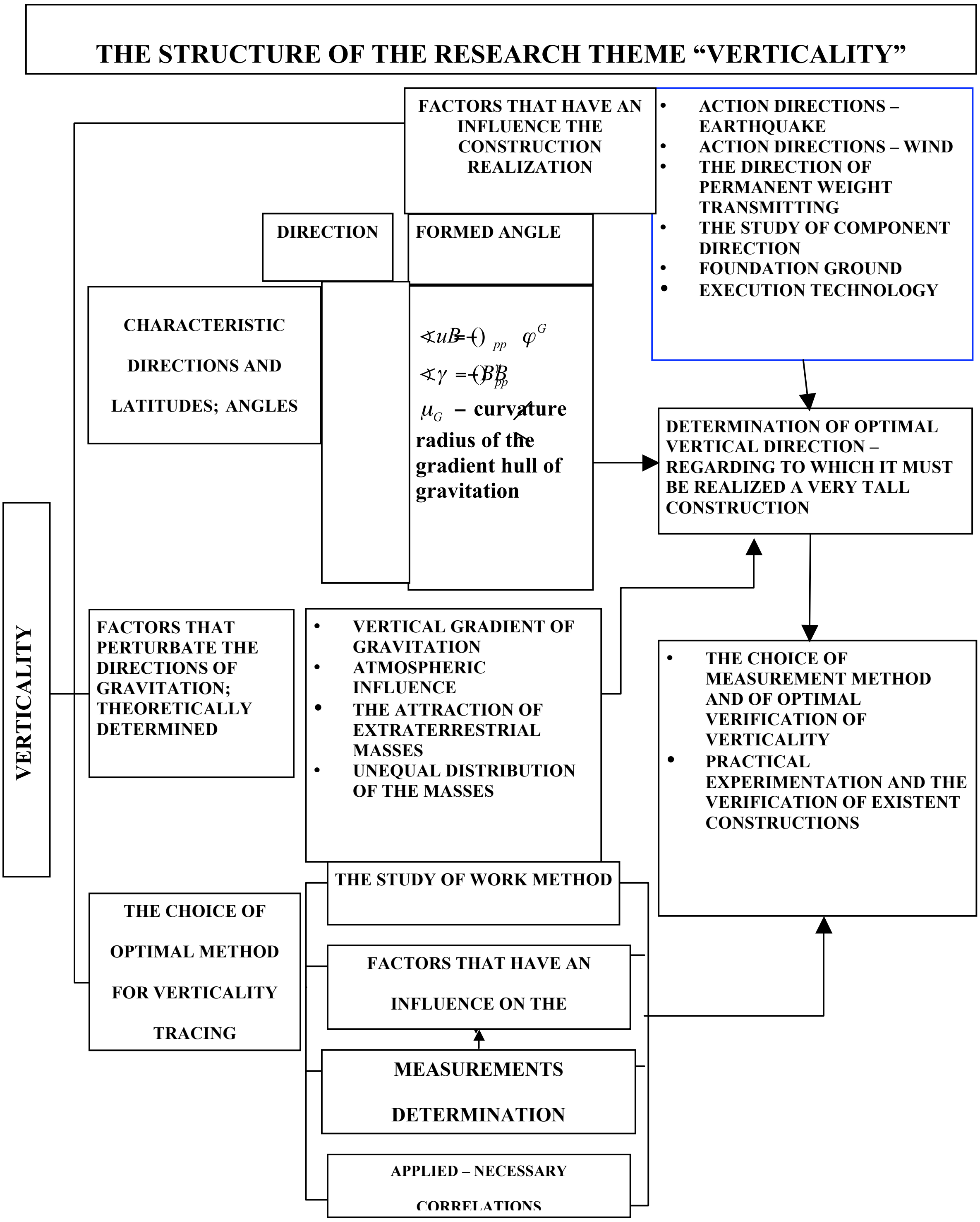

Figure 6

Correctly approached, the proposed problems regarding the technical assistance through the execution or engineering works of time behavior tracing may lead to the proposed scope, providing that for structures design will be calculated the mentioned factors influence, and, in the execution process are strictly respected the design and the geodesist engineer's indications. Other domain research directions, in this area:

- making a data bank that includes measurement results of atmospheric factors effects on tall constructions;
- elaboration of deformations and oscillations predictions for tall structures in engineering projects;
- physics interpretation of the deformations including the making of numeric models;
- making of specific algorithms, new devices, equipments and techniques for the topographical engineering measurements;
- improving the design and projecting solutions of the tall structures;
- data storing, data exchange in this area;
- using of optic fibre sensors in this domain;
- improving the methods of monitoring the constructions "health";
- developing of bent sensors with a greater stability that would distinguish the smallest deviations: linear and angular ones, generally the development of non-geodesic methods (in a classical way) for deformations measuring; extending of cinematic measurement's application in geodesic engineering.

5. NEW TECHNIQUES, DEVICES, MANAGER SYSTEMS FOR MONITORING THE STRUCTURES IN DYMANIC REGIME

In order to punctually or continuously record the response of real structures to various stresses, especially wind, earthquakes, or different exploitation conditions, there have been created classical scanners, or laser scanners, video systems, RTK-GPS systems, RTS and TLS system, sensors, sensitive stamps, pendulums, laser levels, inclinometers, accelerometers, and generally, expert or manager systems for monitoring the structures. Typical New Sensors systems which monitor the geometry and deformations of bridges is: linear variable displacement transducers (LVDT – a distance measuring device), vibrating wire strain gauges, foil strain gauges (set up in quarter, half, or full bridge strain configurations), inclinometers, crack and joint sensors, tilt sensors, piezoresistive accelerometers, piezoelectric accelerometers, capacitive accelerometers borehole accelerometers, servo force balance accelerometers and total stations. The sensor network may consist of a dense array of heterogeneous sensors (e.g., strain gages, accelerometers, cameras, potentiometers, … etc.). In addition, the network must be easy to deploy, scalable – allowing for progressive deployment over time, and must allow for local processing and filtering of data, remote data collection, accessibility and control. Communicating with sensors has long been limited either to wired connections or to expensive, proprietary wireless communication protocols. Using a ubiquitous and inexpensive wireless communication technology to create Fixed Sensor Area Networks (FSANs) will accelerate the extensive deployment of sensor technology.
A large part are creations of companies that produce geo-topographic devices, especially Leica and Trimble, but there should be mentioned that there are new companies that are specialized in monitoring the structures in continuous dynamic regime or which produce instruments for this activity, and which have nothing in common with the field of Surveying.

There was a permanent collaboration between the work's designer, the geodesist and executant through the study of separate and cumulated effects of execution errors and basining process on one hand and wind and unequal sunny effects, on the other hand.

6. CONCLUSIONS

Due to ensure safety constructions of the spectacular structures works, the surveying outline methods became compulsory. That's , dynamical surveying has appeared as a new chapter of surveying which plays an important role of monitoring structure's geometry in kinematical conditions: action of wind or non-uniform sunlight. We consider that the main cause of the non-correlation between the lately increasing concerns towards computation to stability and the continuous happening of accidents, malfunctions, catastrophes of the structures is the lack of enough data regarding the in-situ behavior of the designed and executed structures under various combinations of stresses. Precisely here, generally the Surveying, and especially its new chapter, the Dynamic Surveying, have the possibility to connect the broken chain of optimal design in the field of construction structures.

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BIOGRAPHICAL NOTES

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