Considerations regarding structural monitoring, from static to dynamic methods

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Abstract: For a long time "structural monitoring" was equated with "observing the behavior over time of buildings and land", activity taking place in the static area. Usually, the monitoring action ceased when between two measurement cycles there no longer were movements recorded in the category of settlements or sliding. The whole process takes place in static state, the best known methods being the angular intersection for recording slides and the middle geometric leveling for settlement. This paper presents an analysis of the premises(effect of wind, sunshine, earthquake or cumulative effects of these requests) on which the development and evolution of construction structural monitoring methods, from the static to the dynamic and an argument regarding the appropriateness of continuing the activity in the operating area of engineering surveying.

Keywords: structural monitoring, observing the behavior over time of buildings.

1. Introduction

In 1889 George A. Fuller (1851-1900) created, in Chicago, the Tacoma Building, the first structure ever built whose exterior walls were not load-bearing, columns and beams assuming the role of structural elements, thus being the first frame structure. It was obvious that the svelte structure required monitoring not only for static actions, such as land settlement under the foundation, but also for dynamic actions such as the action of wind. But there were no means of recording the excitation (the variable pressure of wind) - response (oscillating movement of structural elements) ratio; they appeared much later with the release of sensory techniques for structural monitoring. For the quality of the construction, a very important function is hold by the geodetic measuring and tracing technologies. These must satisfy the necessary precision on construction's execution phases starting with the design-imposed precisions, then tracing, practically the lead of the phase construction process, carrying forward with the time behavior study both on execution process and during the exploitation. An effect of those anterior presented was reconsideration of calculus methods, of standards, of concepts regarding mathematical modeling in the projecting process of constructions, but it must be pointed a very important fact: no design method can be validated unless after an analysis regarding the behavior through execution and in time of the construction under the action of disturbing factor's action, wind, earthquake, unequal sunny, at this chapter the geodesic measurements being the ones that give possible answers.

Each state has imposed rules and then, periodically, during execution and after a number of years, sometimes up to 20, observed the behavior of a structure in a static way, in terms of evolution over time of the geometrical position of marks mounted on the structural resistance elements. In Romania Norm P130 determines that any building over two levels high should be monitored until the total extinction of movements in plan and space of the marks mentioned, which indicates the effects of external or internal factors on the structural elements.

2. Action characteristics and their classification

During the construction assurance verification is considered:

- permanent actions **PA**, that are applied continuously with a virtually constant frequency, constant regarding time;
- quasi-permanent actions **AQ**, that are applied with high intensity for a long period or frequent;
- temporal variable actions **VA**, whose frequency is varying time regarding, or the load is missing for a long period of time;
- exceptional actions **EA**, that appear rarely having significant intensities during the construction exploitation.

The calculus for the elements and structures is made considering unfavorable combinations, practically possible for the load, called load groups. Will be kept in mind:

a) Fundamental groups (**PA+ AQ +VA**);
b) Special groups (**PA+ AQ +VA+EA**)

3. Variation of the vertical axis of the highest column structures under the sun action

Column structures with closed section (cylindrical or conical section) tolerate a parabolic deviation of the central vertical axis owing to the unilateral warming by the sun action. In practice the deformation model is magnify. Hence the values α' and d', which correspond to a constant slope, are comparable with real one (α and d) which correspond to the vertical axis's attenuation by the sun action. Correlated the dates of the repeated measures made on constructions with various highs (stacks and antenna towers), it can be conclude that the angle variation cross rarely the value of $0{,}2^0$ for stacks and $0{,}4^0$ antenna towers. Linear significance is presented in the next table.

Table 1. Angle and linear variation under the sun action for the reinforced concrete buildings with circular-conical, stacks and TV-towers.

High-H meters	**d́ cm ά=0.05°**	**d́ cm =0.1°**	**d́ cm =0.2°**	**d́ cm =0.3°**	**d́ cm =0.4°**
10	0,9	2	3	5	7
20	2	3	7	10	14
50	4	9	17	26	35
100 metal stack from Baia Mare,	9	17	35	52	70
200 stack from Dej,	17	35	70	105	140
300	26	52	105	157	209
352 stack from Baia Mare,	31	61	122	183	243
400	35	69	140	208	273
500	44	86	175	260	342
550 TV towers from Montreal and Moscow	49	95	193	286	377
600	53	103	211	312	409
700	62	120	246	364	479
800	71	136	281	416	548
1010 stack design, Australia, Burunga, 2011-2013	100	170	352	518	688

The effects of this evolutional process are can be classify in the following two groups:

1^0 influences of the vertical axis attenuation to the building functionality

2^0 variation vertical and radial stress in structure (estimated by ACI 505-54/98).

4. General problems about the wind action to the cylindrical buildings

The wind represents periodical or quasi-periodical, a stress factor on some time interval for highest building. For the buildings with high greater that 200 m and conical form (stakes, towers, antennae) the study of wind influence is difficult by reason of some factors, as follows:

- Variation on high of the speed wind (so, implicit the pressure variation) is different for other buildings;
- Increase the siaj zone, hence the simulation possibility for some adapted hypotheses are minimized;
- Non existence of some technical studies about the behavior of this structures in superior critic domain;
- Chaotic character of the models behavior in wind tunnel;
- Existence of *n* liberty grade implies an approximate estimations of stress;
- Disaccord between theoretical studies and real model behavior

But, practice presents the next conclusion: reckless of the type of dynamical stress (wind, earthquake, sun action) the building's oscillations in a fixed section are made in ellipsis form. For the whole structure it can be estimated that the figure of oscillations has an ellipsis crosscut. This form of oscillation is an essential characteristic for the reaction of the high structure at the various stress factors. If we analyze the figure of oscillation it can observe that this figure has a quasi-screw ellipsis-conical form. Therefore, the fundamental method for bounding the oscillations is the spire involution or spire of structure. The last research attest, by measures IN-SITU, currency of selected solutions.

5. The seismic action on tall engineering constructions

According to the domain regulation "Standard for anti-seismic design of: housing places, social-cultural, agro-zootechnic and industrial places" code P100-92, there will be kept in mind the following manifestation manners of seismic activity.

a) forces of inertia generated by the vibrations of elevation parts of the constructions, after their involvement in the seismic movement by accelerations of ground-construction interface.

b) efforts generated by unequal movements imposed to the infrastructural parts of the construction.

c) additional pressures came from the forces of inertia created in liquids, powdery masses.

d) the forces came from the leaning and bonding works of the installations, of equipments etc.

6. Coupling of forces – design risk, Consequences of the incorrect estimation of the vertical axis evolution under the stress action

Previously it was accentuated the permanent ellipsis oscillating movement of the highest tubular buildings. Appear the next affirmations:

- Between the sub-dimensioning and supra-dimensioning, the design way alternates in function of the known information and the reference plane of the normative which is in use.

- Information concerning the behavior of the other similar constructions in the same conditions is useful, too. This kind of dates is given only by the direct measures with topological and geodesic methods.
- Variation of the vertical axis for the analyzed structures, with 100, 200 or 350 m high, under the non constant sun action and the wind action, recorded in various weather conditions, could be interested for the designer and for the effecters of other highest buildings, too.
- The classical methods for recording present some disadvantage which limit the informational flux. So, the different ways of recorder go down in value the compatibility of information received from the different sources. Therefore, is difficult to make a date bank.
- Absence of continuity gives to the dates a sequential character. The price is high and the difficulties are various.
- The modern methods, presented in this work, by the new devices and by the measure methods will be eliminate this shortcomings because they can make continuous and homogeneous determinations. But, the results of measures are given rarely and therefore is still difficult to make a dates bank in this domain
- Finely, weather conditions have an effect upon the structure and the device used for record the deviations, too. Hence the obtaining results passes from the functionally aspect to the representative aspect.

7. The response of tall structures on vibrating forces and their effect on inhabitants, considerations regarding the last domain aspects on world level

Swedish and Swiss standards from this domain specifies the frequency, speed, acceleration and amplitude of design (projection) vibrations, maximum admitted of various very high constructions categories and only topographical in-situ measurements can confirm these values. A main preoccupation of the researchers is the analysis of possible loadings combinations, of these effects, of fatale combinations and a reconsideration of actions provoked from the wind as main solicitant environment factor. It's to mention also the preoccupations about determination of interaction of type structure – possible wind effects, the new definitions about solicitant factors, of their combinations scheduled by American standard BS 5950, and especially redefining acceptable limit displacements of the top of tall structures by the same accepted standard among H/300 for columns and singular constructions and H/600 for other categories. Standards of American Construction's Engineering Society ASCE7-02 are giving also trends about minimum factor combinations in tall construction's design. The reaction of structures on apparition of a vibrating source is governed from the next factors:

- the relation between the natural construction's frequency (or of some of its elements) and the characteristic frequencies of vibrations source
- amortization of building resonance or of some parts from it
- diffusion of stress in building or of some parts from it
- magnitude – the size of forces that act on structure
- interaction between the building or its elements and the vibrating source.

Human perception on vibrations – oscillations of tall structures can be considered in or out normal limits, according to many other factors. The American standard DIN 4150 sets up the limits of human tolerability of the vibrations from the buildings where they live or work.

8. Representation conditions of obtaining dates recorded to the vertical axis evolution

a) Exact determination of causes (clime characterization factors), correlated with exact recording of the effects (oscillations or attenuation angle of vertical axis).
b) Continuity of recordings – all over the execution and after that, periodically, in various combinations of forced conditions.
c) Global presentation of the cumulated effects.
d) Split the influences of each forced factor.
e) Minimization of the measure error recordings and put the recordings in similar technique conditions.
f) Removing the environment effects on measuring methods;
g) Removing the errors of construction effects and stabilize in which proportion they influence the results. By distortion it, they are eliminate from statistical dates.
h) Absence of continuity gives to the dates a sequential character. The price is high and the difficulties are various.
i) The recorders will be effectuate for base and for peak of buildings, and from 50 to 50 meters, after two perpendicular directions (preferences NS - VE).
j) Optimal cost. It is relive that for the resident buildings with much more than 200 m high, the investment charge in recording device and usable methods can be by million dollars.
k) Reduced volume of work, decrease the human errors by the methods and by the usable devices. Today this thing is possible.
l) The method must be influenced by the atmospheric factors, in known and control limits.
m) Results of the measures it must to relieve coherently and faithful the relation from the causes and stress factors, from the effects and variation of the structure position in general and the peak in special
n) Dates given by the land surveyor to the designer it must to permit to define the outline of general action – higher structures; particular action – conical structures; special action – height, capacity, environment, base, soil, emplacement, relief, clime, neighborhoods, incidence of the special stress factors

In stage of design, consider that it is necessary to approach cautiously about the possibilities to coupling of stress factors, for highest buildings. 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. So, it can choose the optimal solution in limits to the maximal resistance.

9. An overview of Structural Monitoring and the constructions life-cycle

Security of the civil engineering works requires regular monitoring of the structures. The current methods are often difficult applications, the resulting complexity, dependency from the condition of the atmosphere, and also the costs, limiting the applicability of these measurements. Special attention is therefore focussed on maintaining them in a serviceable condition. The problem is quite complicate as it is function of their age, variety of structural types, different processes of deterioration and increasing volume and composition of traffic. From this viewpoint, surveillance and monitoring have already become a widely used standard. The aim of these activities is first of all to detect the deterioration process already in its initiation phase and to investigate and identify the causes of deterioration. Secondly, by monitoring the progress of deterioration on the different parts of the structure it is possible to give an input for actions aiming at keeping the safety and functionality of the structure within acceptable limits by performing adequate repair actions. Instrumental monitoring is gaining more and more attention as a convenient tool to follow, on a long-term scale, the global performance or the local variations of relevant properties of structures. Mostly developed in the last 10-15 years, this type of approach even not common practice, has been and is used on both new and existing structures to keep under control structures of strategic importance or very deteriorated structures whose critical conditions may require continuous attention. The Initial Structure Evaluation process is the first level of risk assessment for the established inventory of structures. The Initial Structure Evaluation applies established, weighted criteria to gathered existing information and information from one structure visit. The Initial Structure Evaluation will result in the subdivision of structures into five risk assessment structure groups. The Initial Structure Evaluation process is begun with three forms of information being available. The first form of information is the list of all roadway structures apparently overlying abandoned underground mines. The second form is the Structure Visit Form and all information gathered in its completion. The third form is the Initial Structure Evaluation Criteria provided in this section.

10. Selection of the sensing technology

The selection of a measurement technique to be developed in the framework of a research project like STRUCTURAL MONITORING must pursue two main objectives:

1. a new system has to respond to a real need of the end-users,
2. it should constitute an innovative approach in the domain of metrology and present some originality compared to the work of other research laboratories active in the same field.

From the point of view of the end-users seen that a real need exists for short and long gage-length sensors based on fiber optics. These techniques offer the advantage of a small size, insensitivity to electromagnetic fields, currents, corrosion and in some cases temperature variations. Furthermore, optical fibers can be used at the same time as sensors and information carriers, reducing the complexity of the system and potentially allowing the multiplexing of a great number of sensors on a reduced number of transmission lines. Fiber optic deformation sensors, the optical equivalent of rockmeters and inductive sensors, have attracted considerable research interest at the beginning of fiber optic sensor history, especially in the interferometric configuration. Other techniques for deformation sensing rely on micro-bending to encode the deformation in a change of the transmitted or reflected intensity. Some of these techniques have turned into industrial applications. The requirements that a deformation sensor for short (but not dynamic) and long-term monitoring should meet are examined in the next few paragraphs. Low-coherence interferometry in singlemode optical fiber sensors responds to all these requirements:

1 Deformation sensing, A deformation sensor has to measure the distance variation between two given points fixed to the structure.

2 Sensor length, Because of the great variety of structures encountered in civil engineering it is impossible to find a standard sensor length that fits all applications.

3 Resolution and precision, The resolution requirements also greatly vary with the application. If the sensors are considered as replacement of conventional techniques like dial gages, it is important to guarantee at least the same resolution.

4 Dynamic range, For applications in conventional civil structures, in-service deformations larger than 0.1- 1% of the gage length are rare.
5 Stability, Since long-term applications are aimed, the resolution and precision cited above should remain valid even for measurements spaced by years.
6 Temperature sensitivity, All deformation sensors are also to some extent temperature sensors. It is therefore interesting to study the influence of temperature on the deformation measurements.

11. Priority Structural Monitoring recommendations

Structural Monitoring (SM) is an indirect way of detecting the level of damage that has been done to a structure via natural or human induced disturbances. Structural Monitoring was done using wired systems that collected and monitored data from these structures. This was an expensive and inflexible approach because the system could not be easily redeployed if better data collection points were discovered on the structure. Wireless Sensor Networks became a good way to solve this problem, and thereby meet a major requirement for a viable SM system. Autonomous motes could now be deployed over a field of interest while data was collected at a base station . The decision to use WSNs came with a significant tradeoff; bandwidth had to be sacrificed for flexibility and price. The radios on the sensors were not capable of transferring data at very high speeds, which also limited the number of motes that can be part of a single network.

12. Conclusions

Analyzing the complex problems regarding design, projection, execution and topological – geodesic coordination of the construction works and time tracing of tall constructions it can be reached the conclusions:

- The process of very tall structure's, bridges or special construction realizing has known, in the past ten years a development without precedent;
- The surveying – geodesic classic methods of execution's geometric assistance and time behavior tracing have kept their actuality, being used for certain constructions, on recording of some actions and their effects in different precision conditions;
- Have appeared new, unconventional methods, thanks to development of special constructions domain (tall structures, bridges, barrages), of very good performance but expensive, being necessary the carefully design of tracing – execution solutions, practically existing a infinity of combining possibilities for different classic and modern tools, both for studying the causes and the effects of environment factors on constructions;
- There is on the anvil the establish of some general behavior models, valid for quasi – totality of tall structures, particular for some constructions categories (e.g. chimneys) and special, characteristic for structures with similar constructive parameters (e.g. over 200 m in height furnaces, funnel – shaped, of a certain slimness);
- It is necessary to reconsider the execution tolerances for this construction category because the present monitoring technology of the execution permits to obtain high precision results.

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