CONSIDERATIONS ON THE USE OF GEODETIC AND SATELLITE METHODS IN THE STUDY AND MONITORING OF BUILDING BEHAVIOUR

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***Abstract**: Two groups of methods are being used during the complex process of studying the behavior of the buildings: physical and geometrical methods. Within the first group of methods, the setting up of the instruments is made directly inside of the studied building moving thus together with the latter and revealing this the relative values of the deformations. The second group containes the geodetic and photogrammetric methods by whose mean we are determinating the position of some fixed points of the buildings, with reference to the immobile points which are positioned around the building, being this able to obtain the absolute values of the de formations and displacements of the considered building.*

The use of the geodetic and photogrammetric methods do not exclude the use of the physical methods, more than they are strongly related and completing one another.

Within this paper are made some considerations concening the use of the geodetic methods for studying the behaviour of the buildings, presenting the fact that these methods are representing a fundamental system within the experimental and in situ studying process, and that these methods cannot be replaced.

Due to the high precision of the measurements and estimating of the accuracy of the results, the geodetic methods ensure the obtaining of the most realiable values of the parameters characterising the state of stress and deformations of the buildings.

***Keyword:** behavior, building, studied, geodetic, reference.*

1. Introduction

Choosing optimal solutions and the rational operation of buildings requires a thorough and highly complex study, which must be carried out both at the beginning of the construction process, during the conception and design phase, and at the end, during its verification, execution and operation.

The study of model and full-scale constructions involves a test project, in which a complex of measurements and observations are carried out using highly technical equipment and methods. Of the many parameters to be measured/determined, which are usually obtained by calculation, only some can be measured directly from the indications and records of measuring and control apparatus and instruments, these being the measurable quantities. The other quantities are to be deduced indirectly on the basis of mathematical relationships between the non-measurable and the measurable quantities. The accuracy with which the experimentally measurable quantities are obtained also determines the accuracy of the other indirectly determined quantities. The choice of measuring apparatus and methods cannot therefore be made by chance, but there must be a correlation between their sensitivities and accuracies, so that the value of a quantity which cannot be measured directly is obtained with appropriate accuracy, irrespective of the experimentally measurable quantity from which it is deduced. The precision of the results also depends on the precision of the measurements made, which must provide sufficiently reliable values for the parameters and indices that characterise the construction under study as completely as possible.

2. Objectives of construction testing and monitoring of *in-situ* performance of constructions

The purpose of building tests is to establish the numerical values of the parameters that characterise the building from a physical-mechanical point of view and to clarify the overall characteristics of a building or building element, in the form of coefficients that characterise its behaviour under certain stress conditions, either specific to the operating process or arising in exceptional circumstances. Tests may also be carried out in order to clarify the specific features of a type of construction or a construction solution, with the aim of generalising the results to other constructions under different operating conditions.

Systematic organisation of test work in construction and statistical processing of the various tests will allow judicious design, verification of the correctness of the adapted calculation hypotheses, or correctness during the execution process, highlighting the reserves of strength that exist in old buildings that are to be put to another use and how these reserves can be exploited with maximum economy.

Monitoring the *in-situ* behaviour of constructions refers to changes in the position and geometric shape of the assembly or of some of its elements, as well as the detection of evolutionary phenomena that could affect the safety of the construction. By monitoring the behaviour of the construction over time, any irregularities detected can be reported and any necessary measures can be taken to prevent accidents or even disasters. In fact, monitoring the *in-situ* behaviour of the construction is actually a test, but the load is the actual operating load, but the duration of the test is much longer. Therefore, the objectives of *in-situ* monitoring of construction behaviour are also similar to those of experimental laboratory tests with test loads.

Nowadays, the monitoring of the *in-situ* behaviour of buildings has gone beyond the narrow framework of routine maintenance, taking on a pronounced scientific character of study and verification of the most appropriate solutions in operation. After the tragic earthquake of 4 March 1977 in Romania, Law No 8 of 1 July 1977 on "Ensuring the durability, operational safety, functionality and quality of buildings" was adopted, which made it compulsory to carry out quality control of buildings in phases during design and execution, by means of periodic checks of the elements set out in the Technical Book, in the case of building operation. Currently in Romania, Law No 10/1995 on quality in construction has been drawn up, which stipulates that the monitoring of the performance of buildings in operation is carried out throughout their lifetime and includes all the activities relating to direct examination or investigation with specific observation and measurement means, in order to maintain the requirements.

Concurrent analysis and exploitation of laboratory, model and full-scale experimental research results with the results of design calculations and the results of the following the processing of the measurements and observations made during the monitoring of the in situ behaviour, represents a particularly valuable material for the realisation of optimal solutions from a social-economic point of view, ensuring the lowest possible investment. Optimisation of construction has the effect of eliminating oversizing and thus reducing costs.

3. Choice of measurement methods and periodicity of measurement cycles

The generally small and very small values of the changes suffered by the buildings under study make their measurement a most difficult operation. However, the progress made in the production of measuring apparatus and instruments, as well as the continuous improvement ofmeasurement and data processing methods, has made it possible to obtain the best results in determining the parameters characterising the building.

The choice of methods and apparatus is a most difficult operation, depending on the following general criteria:

- test objectives and measurement parameters;
- the static and dynamic nature of the stress on the building elements;
- the expected magnitude of the parameters to be measured and the conditions of the expected required accuracy for each measured magnitude;
- the intended purpose and the nature of the stress field - axial, planar or spatial;
- the nature of the material from which the construction element is made and the gradient of stresses;
- the length of time during which the measurements are to be carried out;
- the number of measuring points, their arrangement in space on the building under study and their accessibility during the test;
- environmental conditions, in the laboratory, indoors or outdoors;
- the dimensions and shape of the constriction elements on which the measurements are to be made and the place available for placing the measuring instruments;
- the economic criterion of the means invested in the test and the time available.

The choice of measuring methods and apparatus requires that the specialists involved have a thorough knowledge both of how the construction under study works and of the optimum possibilities afforded by the measuring methods and apparatus available to them.

Over the years, several systems have been tried to classify the methods of survey and observation, depending on the type of deformation, the type of apparatus and the location of the apparatus during survey. Practice has shown that a correct classification can be made according to the location of the apparatus during the survey. From this point of view, measurement methods can be divided into the following groups:

1. Physical methods, where the measuring instruments are fixed directly to or within the construction and where the instruments move with the construction. These methods measure the relative magnitudes of deformations. The study of physical methods, measuring apparatus and methods are extensively presented in the monograph "Încercarea construcțiilor", edited by Ștefan Bălan and Mircea Arcan [1].

2. Geometric methods, which relate the positions of certain fixed points on the construction, called control points, to several fixed points located in non- deformable terrain and outside the area of influence of the construction, forming the support network or general reference system. These methods, which include geodetic and photogrammetric methods, are used to measure the absolute magnitudes of the plane or spatial deformations and displacements of the buildings under study.

The use of these methods may be done separately or in combination, depending on the nature of the parameters to be tested, the stage of the test and the location of the test or monitoring over time.

The study of constructions by physical or geodetic methods is carried out according to the test plan drawn up before the start of the research. Primary data are obtained by making cyclic measurements of distances, angles, level differences, etc. In the laboratory experimental tests, these cycles correspond to the loading-unloading stages in all research situations. In the final phase of the research, when monitoring the in situ behaviour of the constructions studied, in execution and operation, cyclic geodetic measurements are more frequent during execution, and after commissioning, and increasingly rare as deformations and displacements are extinguished and the constructions stabilise in space.

4. The use of geodetic methods in the study of the behaviour of constructions, subjected to various static or dynamic stresses

In current practice, geodetic methods are widely used, especially in the final stages of construction and observation of the construction in execution and operation, when monitoring the *in-situ* behaviour of constructions, subjected to various stresses. The changes produced on constructions can be due to:

- groundwater level variation;
- water pressure and wind action;
- the action of the weight of the building itself on the foundations;
- seismic and microseismic phenomena, etc.

In recent years, with the deepening of studies on the optimal conditions of application, as well as the introduction in practice of high-precision measuring devices, geodetic methods have been applied with remarkable results also in the initial phase of experimental study of the construction, in laboratory tests on models and at full scale.

It should also be pointed out that geodetic methods for measuring building deformations and displacements can also be extended to the terrain of the building site, as well as to the entire region undergoing deformation.

Depending on the character of the deformations, geodetic methods are classified as follows:

a. **Methods for the determination of horizontal deformations and displacements** (trigonometric method - microtriangulation, method of alignments, method of precision planimetric paths - polygonometry).

b. **Methods for the determination of vertical deformations and displacements** (high precision levelling method, trigonometric precision levelling method, hydrostatic levelling method).

c. **Methods for determining the inclination of tall buildings** (vertical design method, coordinate method, foundation settlement measurement method).

The use of geodetic methods involves the creation of a network of fixed points or landmarks on the ground, in the area of the construction under study, forming the base or reference network, to which the position of control points or sight or survey marks, fixed to the construction and moving with it, is related. It should be noted that the reference network includes both fixed and movable points.

In recent years, important studies have been carried out on testing the stability of fixed points of the reference network, for direct and rapid determination of the deformation vector on the basis of cyclic variation of elements measured directly on the ground (distances, horizontal/vertical angles, level differences), optimal conditions for the application of methods for obtaining the most probable values of the construction parameters, semi-hard or hard calculation algorithms, mathematical models for assessing the accuracy of the final results, the use of statistical procedures for estimating accuracy, programs for automatic processing of the huge volume of measurement data, etc. [2].

The advent of modern technologies in recent decades has allowed their use in monitoring, mainly large/massive constructions. Thus, the TLS (Terrestrial Laser Scanner) laser scanning method, the GNSS satellite technology method, hybrid monitoring systems are being used by integrating GNSS receivers with other sensors. With improved GPS accuracy, coupled with hardware and software advances, it has been possible to achieve continuous, independent, real-time construction monitoring with sub-centimetre accuracy. However, the sources of unmodelled errors still affecting GNSS technology, as well as technical limitations imposed by the current state of development and high equipment costs, have led to the reduced use of satellite technology for large-scale construction monitoring.

Knowledge of the possibilities presented by geodetic and satellite methods by specialists concerned with construction testing and the involvement of geodetic specialists in the highly complex problems that arise will allow the most useful methods of measurement and data processing to be chosen, on the basis of which the state of stress and deformation of constructions can be established.

5. Conclusion

As a final conclusion, it can be said that at present, technological and scientific progress has led to a situation where there are methods and techniques necessary for a good performance of the activity of monitoring the behaviour of buildings, which in turn are becoming increasingly complex. This makes it necessary to constantly strive to improve the methods used, the equipment, and the automation of the processes of geodetic data acquisition and processing.

The introduction of GNSS technology and the continuous improvement of GNSS systems has made it possible to use this technology in the field of building performance monitoring. Combining data obtained from AMCs (measuring and control devices) with those obtained from geodetic measurements, it is possible to obtain even more precise data that characterise the behaviour of the buildings under study over time in a very accurate way. Developments in computing technology, software and methods of data collection and transmission make it possible to obtain accurate results in real time, enabling immediate action to be taken and avoiding loss of life or damage to property.

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