THE USE OF PHYSICAL AND GEODETIC METHODS IN TRACKING THE CONSTRUCTION ACTIVITY BEHAVIOUR

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Abstract: *Evolution of surveying equipment, computer engineering, computer programs and methods of collecting data and transmitting them now allow the combination of physical and geodetic methods in construction activity tracking behavior. This can be integrated into a hybrid system several sensors with complementary characteristics, in order to exploit the strengths of each sensor and to obtain a full spectrum of observations, when some sensors shows its limits. It also can determine interdependencies between environmental factors and changes both the shape and absolute position of the building.*

Keywords*: behaviour, tracking, multisensory systems, expert systems, monitoring.*

1. Introduction

Optimal solution for the rational design and operation of buildings, requires a thorough study and high complexity, which is necessary to perform both at the beginning of the construction, design and planning phase, and finally, the verification phase construction, implementation and operation.

Unless otherwise obtained through experimental testing laboratory construction phase, many other items can be known and based on experience in a long time, based on the study and analysis of behavior in situ construction, operating conditions. Tracking behavior while construction is in fact a special type test generated primarily by the need to ensure operating safety. The basic goal is often filled with scientific research.

The development of measurement techniques has led to the opportunity of observing and highlighting the behaviour of the buildings studied.

Several classification systems of research and survey methods have been tried in the course of time. Thus, there are classifications according to the strains and devices type, and according to where they are located during the research. Practice has shown that a correct classification can be based on the device's location during the research. From this point of view, the methods can be divided into:

a. Physical methods that require setting the measuring devices straight on or within the construction studied, and where the equipment moves along with the construction. The relative magnitudes of deformation are measured through these methods. Depending on the parameters to be measured, this group includes:

- **measuring the linear displacements and deformations** (subsidence, arrows, horizontal displacements) using the arrows amplifier, the rod comparator, the wire comparator (for remote displacements)
- **measuring the angular displacements (rotations)** by using the arm inclinometer, the level and the pendulum inclinometer;
- **measuring the relative sliding displacement** by using the callipers or the rod comparator;

➢ **measuring the specific deformations** by using the tensometers and the electrical, mechanical, optical, pneumatic, photo-elastic or electro acoustic (vibrating string) strain gauges;

➢ **measuring the dynamic displacements, velocities, accelerations and deformations** by using the vibration meter, the vibrograph, the seismic recording accelerometer, the electro-dynamic, piezoelectric or resistive accelerometer, the seismometric gauge, the magneto-electric recorder, the cathode-ray oscillograph;

➢ **measuring the expansion joints deformations** by using the tele-extensometer, the joint micrometre.

The physical methods are widely used in studying the conception and design phase of constructions, in laboratory testing (on models and at natural-scale), as well as in monitoring the constructions' behaviour in time.

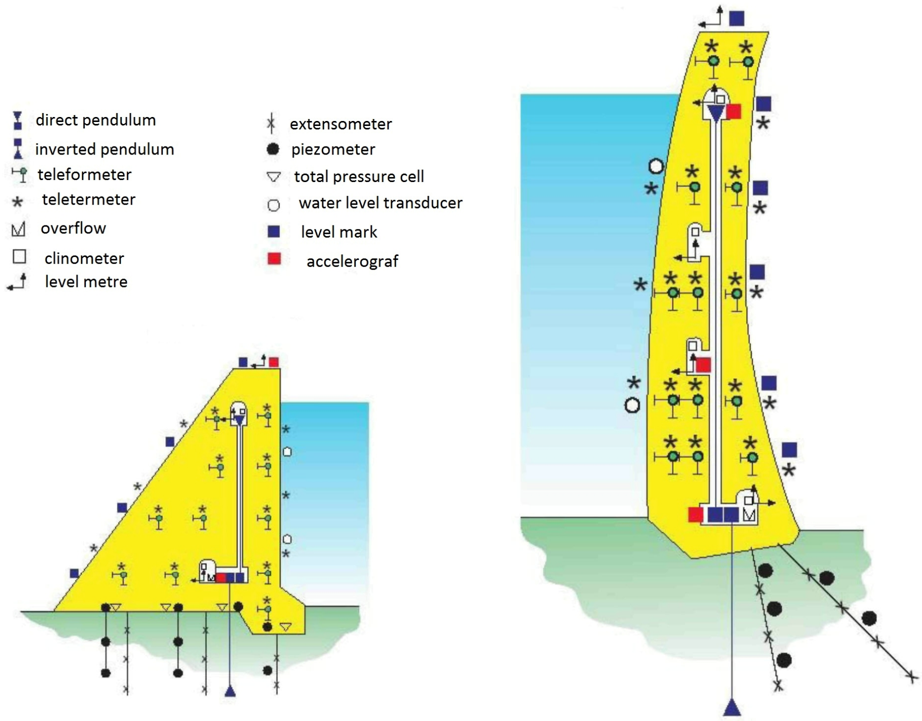

Fig. 1 Endowment scheme with measurement devices for concrete dams (SISGEO)

b. Geometric methods that report the position on the construction of certain fixed points called checkpoints, at fixed locations, outside the building, on stable land and outside the building influence area, forming the support network or the general reference system. The absolute sizes of constructions' displacements and deformation are measured through these methods. This group includes the geodetic and photogrammetric methods.

The geometric methods find a wide use in the final phase of operation, in tracking the construction's *in situ* behaviour.

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

It is noted that geodetic measurements can be extended to the construction's location area and to the entire region suffering deformations.

2. Devices and methods for tracking and monitoring the behavior of buildings using physical methods and geodetic methods

In the following we will present some of the most important devices and methods used in monitoring the behavior of a building.

2.1. Pendulous measurements in wells

Of the many measurement and control devices located in a dam body, the swing plants are from the most important.

The horizontal component of the resultant forces acting on a building prints a horizontal displacement to the construction. Along with increasing deformation, increases the danger of construction damage and destruction.

Pendulous measurements in wells are meant to determine:

a) Measuring the horizontal displacement of each point of the vertical axis Z resulting in: the shape of the bending curve in plane Y – Z, perpendicular to the direction of water flow, and the shape of the bending curve in plane Z – X, parallel to the direction of water flow.

b) Measuring the vertical displacement (subsidence).

The measurement principle

Pendulous installations are mounted to a dam's well, and by mechanical or optical means, one can observe the movement of the wire to a zero starting position.

It is advisable to make the pendulous measurements concomitant with the inclinometer ones. The inclination angle of the concrete block is set both with the inclinometer (α_c) and with the pendulum (α_p). If the below condition is met,

$$\alpha_p = \alpha_c$$

then the concrete block has suffered a slope, and if equality is not met, namely

$$\alpha_p \neq \alpha_c \quad ,$$

then the concrete block has an arrow as well.

The components of a pendulous installation

A pendulous installation is made on the principle of plumb line. It consists of a steel wire, devices for intermediate fixation and suspension of the wire, a weight and a reading device. The suspension point is chosen at an as high as possible level of the dam profile, usually at the canopy, and the deformations measurement is made at an as low as possible level, at the foundation or under the soles of the dam. If the well is extended to the foundation rock, then, by using these measurements, one can set the foundation soil properties and changes. The devices for intermediate fixation of the wire are used in order to determine the dam inclines at several different levels. The reading device can indicate only the value of the relative displacement of a point (located for example in the canopy) towards the base, for, in turn, the base point moves along the foundation soil.

The displacements determined above can be translated into digital signals that can be sent to a specialized software and integrated in the general analysis of a multi-sensory system.

Determinations are recorded and can be viewed at any time in tabular or graphical format and can also be compared to those provided by other sensors indicating physical or geometrical sizes.

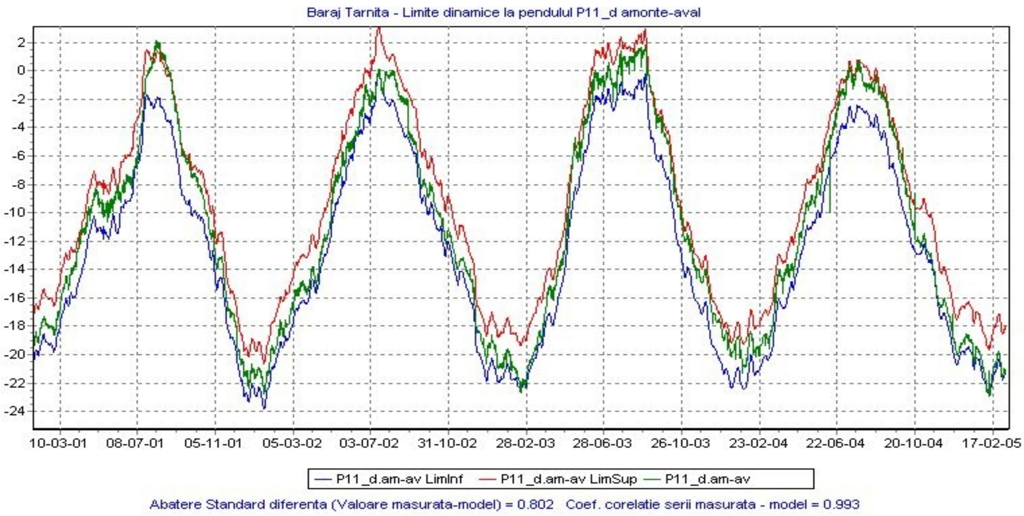

Fig. 2 Example of using the limits for the measurements analysis on a pendulum

2.2. Robotic total stations

Regarding the use of total stations in monitoring the construction activity, the overall trend is of going towards the robotic total stations, permanently placed on the network pilasters, so that they can provide at any time a series of measurements, free of the problems caused by the visit of a specialized team in the objective perimeter. There are also eliminated the subjective errors due to operators and to different equipment used on different series of measurements. However, perhaps the biggest advantage of robotic total stations remotely controlled by specialized software is the fact that data sets can be obtained at any time regardless of time, seasons, weather conditions etc.

Thus, for measuring the angles and the distances, robotic total stations with automatic recognition of prism are used. They are mounted on concrete pillars. Where necessary, they are protected by "shelters" made of special glass walls in order to allow observation.

Fig.3 Robotic station location

The prisms mounted on the dam body evidence the points monitored on the objective of the study.

Fig. 4 Prisms mounted in the body of the dam

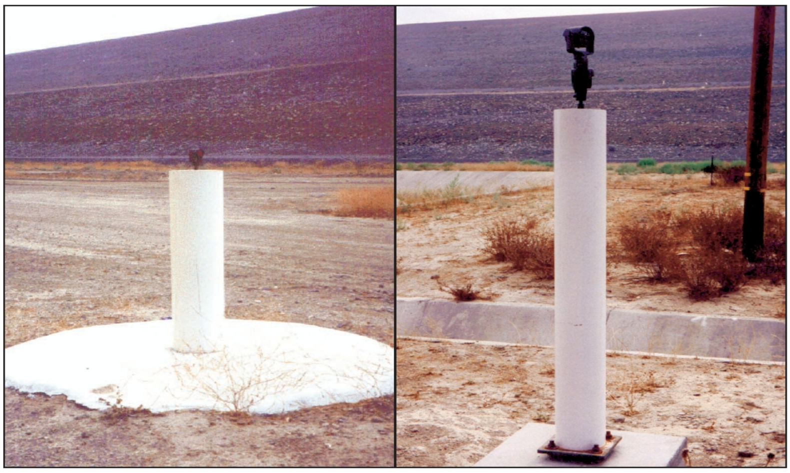

Fig. 5 Prisms mounted on pillars

The power supply required for the operation is carried out from the electric mains or, if the access to it is difficult, it can be made by means of photovoltaic panels. (Figure 7)

Fig. 6 Total stations supply with photovoltaic cells

Using robotic total stations helps eliminating the subjective errors due to operators and to different equipment used on different series of measurements. However, perhaps the biggest advantage of robotic total stations remotely controlled by specialized software is the fact that data sets can be obtained at any time regardless of time, seasons, weather conditions etc. Thus, in case of extreme weather, team of specialists’ visit and measurements by classical methods may be impossible.

2.3. GPS Technology

Along with the development of GPS technologies and improvement of receivers' precision, one may consider at this time using this technology in monitoring a building's behaviour.

Fig.7 The location of GPS stations and supply system

As with any technology, in this case too, we can discuss the advantages and disadvantages. Thus, the major advantage of this technology is that we can get data on a building's movements in real time, at its appearance. The disadvantage is however the relatively low precision especially in terms of vertical displacements. In addition, the costs of placing a GPS receiver on each landmark pursued, their power supply, transmitting data from them, and providing visibility to satellites, leads to much higher costs than using robotic total stations.

2.4. Multisensory systems

Because of the shortcomings of the different tools used for monitoring the construction's behaviour in time, the best way to eliminate them is to create hybrid-monitoring systems incorporating several types of sensors, using the maximum possible of each.

Given the above technologies (both of the category of measurement and control devices, embedded in the building, and of those outside the construction) and using the computers high performance (both hardware and software), we can delineate a hybrid-monitoring system that will use information both from the building's body (such as those provided by the pendulous measurements) and information from outside it. Parallel processing and interpretation of these data sets, synchronized in terms of time, lead to a broader and more accurate understanding of the phenomena that occur both in the body of such buildings and in the land that surrounds and often supports it. Experts in the field have thus the opportunity to predict and to intervene effectively if dangerous evolutionary phenomena occur in terms of construction's safe operation.

Up to the present, we can say that both in terms of accuracy in determining the displacement given by the deformations occurring in the body of the dam, and of the geological phenomena around the building, robotic total stations are the first choice in determining the displacement vectors. However, their main disadvantage is that they do not provide information in real time, and they sense the production of a sudden failure or deformation only when performing a new measurements cycle, at the time it is scheduled by the lens administrator and implemented in the software managing the whole system. This disadvantage can be eliminated by acquiring and integrating in the architecture of the software monitoring the data from the measurement and control devices fixed in the building’s body, which instantly seize sudden failure phenomena. Thus, pendulous measurements and other measurement and control devices installed on building’s body may catch sudden displacements on the entire height of the building. The sudden variation of the data provided can be the alarms that can make the software order a series of measurements towards the robotic total stations. Thence, a GPS receiver installed on the building can also “wake up” the surveillance system established by robotic total stations, given that it provides the absolute displacement size of the building (of the building’s point on which it is placed) .

2.5. Expert systems

As already seen, integrating the data provided both by a building’s equipping measurement and control devices and by different geodesic methods for determining the absolute displacements, leads us to the creation of an automatic system. The system, as it has a well-structured software platform, can make decisions with or without a specialist’s confirmation in order to avoid potentially dangerous situations for both the building itself and for the people around it. Such a system is called expert system and it has the advantage of working faster than human experts, making decisions faster. Expert systems include consistent information (structured in the same way) about an environment subject to chance and they make it possible to distribute information to many people in different places. Expert systems do not get bored, do not forget, do not get tired and improve the knowledge of the best experts. Copies of the expert systems can be made, while training new human experts takes time and money. They can be integrated with other systems and can work with incomplete information.

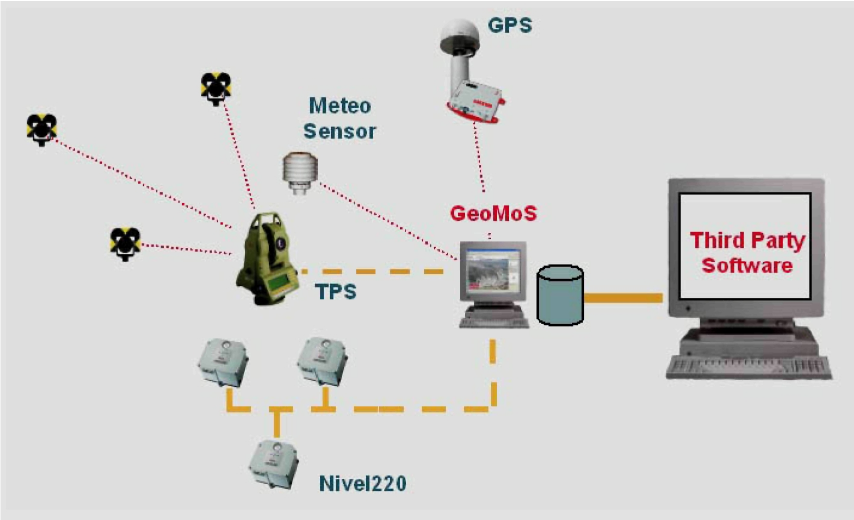

Fig. 8 Example of expert system with multiple sensors

3. Conclusions

Given the experience acquired during decades of monitoring the constructions by using modern methods based on electronics development, we can state, as a conclusion, that the hybrid systems are the future of this activity. At present, the progress of all the technologies presented, both in terms of measurement and control equipment, and in terms of geodesic technologies, and finally yet importantly, the computers, allow us to integrate the data sets provided in order to obtain a superior interpretation of a building's behavior in time.

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