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Synthesis of Reviews on Auscultation, Approaches, and Methods for Engineering Structures

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Abstract

Topometric auscultation is used to monitor the durability of structures, measure deformations linked to the structure of a structure or to the movement of the ground over a part of the globe, set up warning systems, etc. It first appeared as a visual method and rapidly evolved through the various techniques used. Some of these techniques using topography are used in several fields (civil engineering, geodesy, topography, mechanics, nuclear engineering, hydraulics, physics, etc.). These topometric techniques have undergone major changes as a result of technological advances, growing needs in the monitoring of movements or deformations, increased requirements and new challenges. The methodology adopted depends on the measuring instrument used, the parameters to be estimated and access to the area to be measured. There are two types of methods: destructive and non-destructive. In addition to the visual method, they can also be classified as mechanical, physico-chemical, dynamometric, electrophysical and geometric. The estimated parameter varies according to the methodology adopted. It can be defined by coordinates, distances, potential, electrical resistance, etc.

Keywords

Auscultation, Engineering Structure, Topometry, Method, Review

1. Introduction

Auscultation is a method of checking structures for inappropriate behaviour. It takes the form of a measurement-based diagnosis to determine the operating state of a system [1].

In research, the auscultation technique is applied in a number of fields, including civil engineering (through engineering structures), the exploitation of underground resources, medicine [2] [3]; geophysics [4] [5]; hydraulics [6] [7]; etc.

In most situations, this monitoring technique enables displacements to be quantified on the basis of vibrations and deformations. These vibrations and deformations are most often caused by the loads applied to the structure, stress due to continuous loading, local soil displacement, secondary stresses, local weather conditions, seismic shocks, etc. The vibrations may come from natural or artificial sources. Vibrations may come from natural sources or be man-made. In this case, the deformation is due to an external force or effect applied to the structure [8] [9].

Therefore, monitoring becomes a complete process, encompassing the collection and analysis of information. The observation, measurement, analysis and prediction of the behaviour of the object to be monitored must be carried out by an appropriate device.

We can, therefore, consider auscultation to be all the methods and resources used to study or monitor the behaviour of targeted structures or sites.

To interpret the measurements, it is necessary to know whether the deviations are due to movement of the structure or to an error or fault in the measurements.

Classical surveying instruments were used to begin topometric auscultation. These tools have grown rapidly due to recent technological advances. As a result of this evolution, different approaches and methods have been developed, giving new advantages to topometric methods, although there are limitations on both sides.

The study's aim is to review auscultation methods and their advantages and limits.

2. Review of Auscultation Methods

Maintenance and monitoring are inseparable in the evolution of technical structures. In the case of dams, for example, historian Jean Louis Bordes has attempted to retrace their history [10].

In his research, he pointed out that the engineer Alexandre Collin had made a number of observations in the field, recording the shapes, their relationship with the layers and the conditions that created these ruptures. This visual method that Alexandre Collin tried to use has been in use since 1846. We have thus been able to present the beginning of the implication of the idea of the so-called dam monitoring method of 1846.

According to Jean Louis Bordes [11], during the seventeenth and eighteenth centuries, the visual method preceded any measurement operation and contributed to the formation of the memory of dam builders. Subsequently, the adoption of new measuring instruments and procedures was motivated by the need to respond to the concerns of those involved in construction in order to understand how the structures functioned and to guarantee their safety at all times. In addition to leakage flow measurements through structures, the first to be carried out were topometric displacement measurements. In 1852, topographic surveys were carried out on the masonry dam at Grosbois, in the French department of Côte d'Or, in order to monitor the displacement of the dam. The importance of steel structures and the need to compare dimensioning methods with the actual behaviour of structures led engineers to develop measuring equipment.

In India, at the end of the 19th century, piezometers were used to record observations that enabled flows to be captured. In 1907, English engineers used instruments of this kind in the same country to calculate the free surface of the water table installed in a homogeneous earth dam. From 1917 onwards, the United States used piezometers in earth dams, and later improvements led to the creation of cells for measuring hydraulic pore pressures.

In 1922, in the United States, the arch dam instrumentation programme led to a better understanding of the mechanical behaviour of arch dams, in order to reduce costs and increase their safety. Fissurometers and inclinometers were used as part of this programme.

As well as providing a better understanding of the behaviour of the structures, the lessons learned from the measurements are used to improve the equipment. This was the start of a period of innovation in measuring equipment.

Between 1950 and 1960, faced with the need for precision, the existing tools were no longer appropriate. In some cases, topographic measurement tools proved more satisfactory [12].

According to the literature, it can be classified according to several methods and approaches:

- Visual auscultation [11].
- Auscultation using conventional instruments [13]-[21].
- Auscultation using GNSS receivers [22]-[26].
- Auscultation by developing and implementing new techniques [27]-[33].

This evolution in methodology is justified by the development of measuring instruments. These measuring instruments have evolved thanks to new information and communication technologies. This evolution is partly justified by the development of electronics accelerated by the Second World War, the invention of radar and the arrival of computers [34].

The development of these tools has resulted in simpler methods and shorter processing times.

On the one hand, the limitations of the instruments used lie in the need for qualified personnel and the sometimes-onerous costs involved. On the other hand, in-depth analysis, knowledge and understanding of the measuring instruments and the influence of certain external factors are still issues to be resolved, depending on the method. The major limitation remains the inability to link the nature of the deformation to its quantity.

The disciplines involved include topography, photogrammetry, lasergrammetry, mechanics, civil engineering, acoustics, seismology, geodesy, geotechnics, etc.

3. General Methods of Auscultation

There are two types of auscultation methods: destructive and non-destructive.

- They can be divided into six main categories:
- Visual methods include techniques involving surface inspection by direct or indirect observation.
- Mechanical methods involve techniques that apply force to the structure or material. They also include pull-out and penetration methods and are most often used in Geotechnics.
- The physico-chemical method is based on an assessment of the state of the material. The use of indicators makes it easy to interpret the state of the material. The electro-physical method groups together methods using electrical, magnetic or related measurements. It includes thermography, ultrasound, radiography, etc.
- Dynamometric methods are similar to mechanical methods. The difference is that one is destructive and the other is non-destructive.
- It includes support lifting, test loads and the use of sensors to measure response.
- The geometric method groups together techniques involving the recording of displacements. The principle of the general methods can be summed up as a control of the surface or structural aspect of the engineering structures, a physico-chemical analysis of the behaviour and the recording of displacements.

The equipment required and the estimated parameters vary according to the method used. This diversity depends on the method, the disciplines and the objectives sought.

The simplest method is the visual method. However, this method is still inadequate.

Table 1 summarises the categorisation of monitoring methods, the equipment required, the estimated parameters and the advantages and limitations of each method.

Table 1. Categorisation of auscultation methods.

Category	Type	Definition	Principle	Materials required	Estimated parameters	Advantages	Limites
Visual method [14]	- Non destructive	- Control of surface appearance by direct or indirect method	- Analysis and recognition of visible damage to the structure	- Human eye - binoculars, cameras, video films, endoscopes, fibre optics, surveying instruments	Surface appearance	- Allows recognition and diagnosis - No need for contact - Enables each element to be analysed in detail - Allows visible parameters to be identified - Fast and simple for coarse deformations - Non-destructive method - Points to the causes of deformation	- Not sufficient - Detection of visible damage - Relies on the knowledge and expertise of the observer - Limited to gross deformations - Method limited to superficial damage - Requires in-depth analysis to invalidate or confirm interpretations

Continued

Mechanical method [14]	- Non destructive	- Technique acting on the structure or material - Hammering - Sclerometer	- Auditory assessment of changes in sound response and detection of local disorders - Assessment of the material's absorption capacity	Hammer-type metal rod - Geophone, Acceleration sensor	- Dynamic modulus of elasticity - Compressive strength	- Allows local assessment of material quality	- Locally destructive - Non-repeatable in the same places
Physico-chemical method [14]	- Destructive	- Technique using physical or chemical analyses	- The absorption principle is commonly used	- chemical indicators - Lab analysis elements	- Concrete permeability - pH	- Easy to use - Confirms the phenomenon detected	- Rough results
Electro-physical method [14]	- Non destructive	- Electrical and magnetic measurement	- Principle of ultrasound - Reinforcement detection principle	- Potential probe Electrical resistance, thermography	- ddp - Detection of rebar location, cable breakage, concrete moisture, rebar corrosion, etc.	- Excellent quality of results	- Sophisticated equipment required - Qualified personnel - Requires good calibration
Dynamometric method [14]	- Non destructive	- Measuring or applying force to a structure	- Principle of extensometry	- Mechanical comparator, inductive displacement sensor, micrometer, etc.	- Linear deformation	- Produces good results	- Careful installation is imperative
Geometric method [14]	- Non destructive	- A technique that involves recording movements	- Principle of topography	- Graduated ruler, precise measuring device	- Difference in altitude, differences in coordinates, etc.	- Simple installation - Easy to install	- Complex interpretation

4. Geometric Methods of Auscultation

Geometric surveying methods can be grouped into five disciplines: topography, geodesy, photogrammetry, radargrammetry and lasergrammetry.

Each method uses specific instruments and has its own strengths and weaknesses.

The overall principle is that of auscultation, which consists of comparing the results of two measurement campaigns, deducing the differences noted between these two campaigns, correcting the errors if they are attributable to known external conditions and interpreting the results if they are due to a displacement of the object being auscultated.

The interpretation of the measurement results must therefore take account of the errors. These errors must be within certain ranges if the measurement is to be validated.

The use of various instruments linked to the disciplines involved in monitoring will mean that the principle can be adapted to suit the instrument.

Geometric methods offer the advantage of being adaptable and do not require contact, except in the case of topometric methods. These methods are more often influenced by the measurement conditions.

Table 2 presents the different disciplines of geometric testing, the equipment required, the parameters estimated and their advantages and limitations.

Table 2. Geometric technique of auscultation.

Auscultation discipline	Principle	Materials required	Estimated Parameters	Advantages	Limites
Topography [14] [22]-[24]	- Estimation of variations in results for a variable repeated over time	- Level equipùent, Total Station - distancemeter.	- X, Y, Z, distance - Height, gradient, angle, etc.	- Adaptability, - lightness, - availability	- Influenced by measurement conditions - Requires contact in some cases
Geodesy [16] [17] [27]	- Variation in results from GNSS measurements during two different campaigns	- GNSS Receptor	- X, Y, Z - Distance, phase, etc.	- absolute measure	- Influenced by measurement conditions - Limit to areas not covered
Photogrammetry [30] [32]	- Estimation of the variations between two aerial or ground shots taken of an object under the same conditions.	- Drone, camera, etc.	- X, Y, Z, distance, point cloud, etc.	- Does not require direct contact - Easy to apply	- Influenced by atmospheric conditions - Limited to areas not covered - Very high acquisition cost - Heavy processing
Radargrammetry [26]	- Estimation of the displacement of each pixel in images collected at two different times by comparing phase differences.	- Radargrameter, ground radar, telephone sensor, etc.	- X, Y, Z, point cloud, phase, etc.	- Suitable for monitoring structures - Non-contact measurement - Capture at any time - Unaffected by atmospheric conditions - Generates a dense cloud	- Limited products on the market - Very high acquisition cost - Heavy processing
Lasergrammetry [26] [32]	- Evaluation of the point deformations of an object and its shape by comparing two clouds of points taken at two different times.	3D scanner, telephone sensor	- X, Y, Z, distance, etc.	- Does not require contact - Generates a dense cloud - Not influenced by atmospheric conditions	- Very high acquisition cost - Heavy processing - Cloud quality independent of colour, material and orientation. Influenced by glossy and retro-reflective surfaces

5. Discussion

Topographic surveying began with traditional measuring instruments. Over time, this technology has improved through the use of total stations with GNSS receivers, lasergrammetry, photogrammetry and radargrammetry. This improvement has enabled the techniques to be upgraded, which can, in part, be linked to the development of information and communication technologies.

Beyond this improvement, certain techniques are still being borrowed. For example, detection sensors and algorithms will be used in monitoring. This borrowing is explained by the introduction of real-time sensor response and uniform data processing.

What's more, telephone sensor technology opens up new prospects and has produced promising results, as in the case of image processing (cloud, etc.).

In addition, telephone sensors are less expensive than other auscultation instruments.

This is why it is interesting to use them as monitoring tools coupled with a monitoring and warning system, at lower cost.

This solution is an alternative for developing countries.

However, the major problem with these sensors or warning systems is the integrity of the data provided.

In short, while topometric monitoring is effective in quantifying displacements, it remains ineffective when it comes to determining the causes of the deformations (displacements).

6. Conclusions

This study reviewed the various auscultation methods and listed the instruments used, the parameters to be estimated, and the advantages and limitations of these instruments.

The auscultation technique has been used in the context of risk prevention, deformation measurement and monitoring of civil engineering structures.

In addition to characterising the behaviour of a structure, this has proved to be the most accessible auscultation technique.

Nowadays, smartphone-based imaging for analysing the behaviour of engineering structures is opening up new prospects in developing countries.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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