The new French interactive Guide for Investigations on Structures

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Abstract

IFSTTAR, in collaboration with the CEREMA, decided to publish in 2015 an interactive guide on the investigations (or auscultation) of bridges which has two main parts. A first part presents more than one hundred auscultation methods for "materials" and "structures" that are sufficiently valid, giving for each method its principle, its field of application, the limits and conditions of use, the specific constraints, the precision of the measurements, as well as elements on the availability and the cost. A second part presents the diagnostic methodologies combining various auscultation methods according to an optimal scheduling in order to know the condition of the structures. The guide is on internet and uses hypertext links to connect all the documents. This guide, which aims to be a simple document to read, pedagogical and didactic, is continuously improved. It may be found at the following address: http://www.ifsttar.fr/collections/CahiersInteractifs/CII1/index.html

Keywords: Structure, bridge, guide, investigation, auscultation, methodology, interactive, diagnosis, evaluation.

1. Introduction

Nowadays, owners and managers of transport infrastructure are more and more concerned by actions related to the heritage management, considering:

1. the decrease in investment programs for the construction of new structures;
2. the aging of the heritage, which results in an acceleration of the materials deteriorations under the environmental exposure conditions;
3. a growing aggressiveness of the traffic;
4. an increase of constraints due to the operation of networks resulting from a desire of the users for a greater availability of these networks;
5. the growing requirement for the safety of use of infrastructures.

This is particularly the case in the field of bridges. Many technical documents are existing in France in the field of:

- inspection and evaluation (with the ITSEOA instruction [1] and the IQOA guides [2]);
- repairs and strengthening (with the European standards of the EN 1504 series for repair products, the French standards of the NF P 95-100 series for the execution of repair techniques, the various LCPC (Central Laboratory for Roads and Bridges) technical guides on repair and protection of

structures, and more recently the guides developed by STRRES (www.strres.org);

- management (with management methods such as the VSC method, the departmental method, ..., and adapted softwares like SIAMOA, OASIS, SCANPRINT, AERO ...).

But, it must be recognized that, as far as investigations on bridges are considered, no reference document is existing in France, except the AFGC-COFREND book on the methodology for the non-destructive evaluation of the deterioration condition of concrete structures [3], and the book on the maintenance and repair of bridges in which chapter 2 deals with investigation methods [4].

That is why IFSTTAR and CEREMA, decided to write and publish a technical guide on the auscultation (investigations) of bridges in order to fill this gap. This action was supported by many bridge managers that were seeking for a state of the art on instrumentation and auscultation methods, as well as recommendations for diagnosis using these methods. Indeed, for at least thirty years, the LCPC (now IFSTTAR) and the network of Road and Bridge Regional Laboratories (now CEREMA) have created a great bundle of auscultation means, and now wish to enhance, improve and complete the methodologies they make available to all owners, bridge managers, project managers, consultants, laboratories and companies involved in the field of diagnosis and repair of structures.

2. Reminder on auscultation

« Auscultation » is a term that is declined in different ways according to professional circles. For some, it refers to all the technical activities implemented to acquire, analyse and interpret measures without a priori as to the purpose of this activity; for others, it refers to the metrological surveillance carried out on structures to monitor them and detect abnormal evolutions (example of auscultation of large dams).

For reasons of cohesion with the structure management policy defined by the documents of the Ministry of Transportation, we will therefore retain the definition given in the technical guide n° 03 of the ITSEOA [5]: "The auscultation is a set of examinations and specific measures making most often use of elaborate techniques, and which aims at better knowing the real condition of a structure to lead to a diagnosis of its pathology ". Thus, it can be considered that auscultation includes the instrumentation and the implementation of tests that may be destructive or not. Some auscultation methods can be applied with a more or less regular frequency to monitor the behaviour of a structure over time; this activity falls within the scope of either enhanced surveillance or safety surveillance as defined by ITSEOA Guide n° 03, and not within the scope of auscultation.

Figure 1 presents the position of auscultation in a bridge management process. The establishment of an auscultation program must follow a thorough analysis of the bridge records and a very detailed examination of the disorders observed during the various surveillance actions (including detailed inspections). In practice, it is necessary to get first an idea of the possible causes of the disorders. Thus, one should not engage in an auscultation if one has not already made a detailed inspection of the structure, allowing to carry out a pre-diagnosis of the pathology and to guide the choice of the auscultation techniques to be applied…

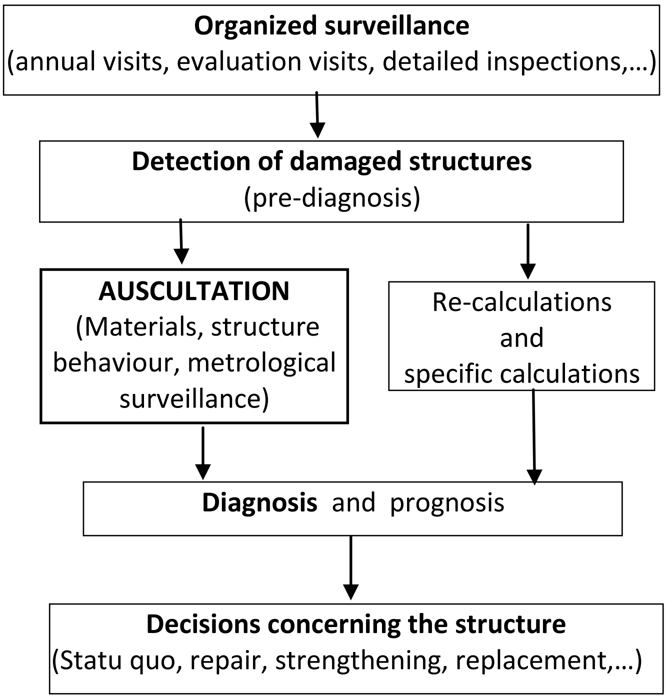

Figure 1 : Position of the auscultation within a management process of damaged structures.

3. Presentation of the Guide

The guide deals with auscultation methods (including instrumentation methods) of bridges in their entirety including those relating to superstructures, foundations, equipments and protective elements. However, it does not cover methods for soil auscultation. The structures targeted by the guide are primarily bridges, retaining walls and covered trenches. But it is obvious that other structures such as tunnels and more broadly civil engineering structures (dams, river and marine structures, airports, sanitation works, hydraulic pipes, water reservoirs, etc. ...), as well as historic buildings and monuments can benefit from some or all of the methods presented in this guide. In addition, it addresses all the main materials used in structures: concrete, metal, masonry, wood.

The guide is divided into two main parts 1) and 2):

1) The presentation of the auscultation methods in the form of a synthetic sheet by method.

2) The presentation of the diagnostic methodologies to be applied in cases of recognition of structure or structural elements, as well as in the most frequent or the most important cases of pathologies.

Its interactive characteristic is justified by the fact that it is on internet (with free download), hypertext links are provided between diagnostic methodologies and auscultation methods, questions or remarks may be posted by visitors and rapid modifications or corrections can be done.

4. Part 1: Auscultation methods

4.1 Sheets on auscultation methods

To date, about a hundred of sheets has been developed for each of the auscultation methods (and sometimes fields of application) which are classified into three main categories:

A) Auscultation on samples;
B) Auscultation of the material in situ;
C) Auscultation of the structure.

The auscultation techniques on samples are classified according to the type of material tested: concrete A1, steel A2, masonry A3). The auscultation techniques of the material on site are classified by type of material (concrete B1, reinforced concrete B2, steel B3, wood B4), then by structural and protective elements (cables B5, waterproofing membranes B6, paintsB7). The auscultation techniques of the structure are classified according to the following headings: recognition of the geometry C1, types of measurement (general deformations and movements C2, local measurements of behaviour C3, forces C4, tests (loading static tests, dynamic tests) C5, and foundation auscultations C6.

Auscultation methods can be linked to several applications. As far as possible, we tried to group the applications and to write only one sheet per method, but this was not always possible because of the specificity of some method in relation with the application. For example, there is respectively a sheet for gammagraphy on concrete and on metallic structures.

Each sheet presents a single canvas with the following five main sections: Principle and short description, application, operating characteristics, advantages and disadvantages, availability and costs, to which is added a list of references (standards, articles, test methods, operating modes, etc.) where these exist. The length of the sheets is not standardized because we consider that it should be adapted to the importance of the method or its complexity; thus, the "principle" or "specific material used" sections may be longer or shorter depending on the amount of information necessary for understanding or description.

Although this guide presents many methods of auscultation, it does not claim to be exhaustive. Among the existing methods, only the methods that have been sufficiently validated by IFSTTAR and CEREMA are included: it essentially contains methods developed and applied by these two organisms, but also some methods developed by other organizations or companies.

4.2 Content of a sheet

Table 1 presents the detailed content of a sheet and explains what is expected for each of the headings. Whenever possible, photographs or diagrams are included in the sheets to illustrate the material used and / or the application of the method onto a structure.

Table 1. Content of a sheet

Principle and short description	
Objective	Defines the utility of the method in the intended field of application
Principle	Defines the physical principle on which the technique is based
Destructive character	Defines whether the method is destructive, semi- or non-destructive.
Maturity	Provides an indication of how old and how reliable the method can be
Specific material	Self understanding…
Application aspects	
Domain of application	Defines the type of structure or element or material to which the method may apply. Also defines the application context of the method
Practical suggestions	List the conditions to be fulfilled in order to apply the method.
Limits of use	Related to the performances of the method itself e.g. acquisition frequency too low to do dynamic measurements, geometric characteristics of the structure (maximum thickness, ...), external environment (usable day or night, ...) etc.
Precision and/or sensitivity	Accuracy, uncertainty, resolution, measurement range, Sensitivity, detection threshold, ...
Staff and skills	Indicates the type of staff suitable to apply the technique
Operating characteristics	
Access to one or two faces	Self understanding…
Traffic cut or restrictions needed	Self understanding…
Productivity and/or sampling	Indicates whether the method is punctual or has high efficiency. Specify the number of information recorded per unit of time or space
Delays for availability of results	Self understanding…
Traffic disturbances on measures	Self understanding…
Environmental disturbances on measures	Self understanding…
Risks to users or the public	Self understanding…
Dimensions - weight	Self understanding…

Advantages - Disadvantages	
Availability - Cost	
Availability	Indicates if the method can be implemented by many companies or laboratories, or is available quickly.
Cost	The cost corresponds to the implementation of the method without taking into account the indirect costs (means of access, restriction of traffic,…). Only a qualitative and comparative assessment of the cost is made by designating it as: Low, Medium or High. To give orders of magnitude, it is considered that a low cost does not exceed a few hundred euros, an average cost is of the order of a few thousand euros, a high cost is greater than ten thousand euros, and a very high cost exceeds one hundred thousand euros.
References	

5. Part 2: Diagnostic methodologies

5.1 Sheets on diagnostic methodology

The diagnostic methodologies are intended to help the experts and managers of structures to combine different and complementary methods of auscultation in order to lead to the diagnosis of a pathology. The guide deals with two main families of methodologies:

D) Diagnosis of the material condition
E) Diagnosis of the structure

The methodologies on the material condition are classified according to the type of material tested, including materials that enter the protection elements: concrete (D1), steel (D2), masonry (D3), wood (D4), protective elements (D5).

The structural methodologies are classified according to the type of structures, the first class being dedicated to methodologies that apply to all structures: generic problems (E1), concrete structures (E2), metallic and composite structures (E3), masonry structures (E4), cable structures (E5), foundations and retaining walls (E6).

Each methodology is written according to a plan that is substantially common and that includes a description of the context with sometimes a reminder of the deterioration mechanisms, the diagnosis methodology divided in 3 steps:

1. Step 1 : Analysis of the structure records
2. Step 2: Detailed inspection
3. Step 3: Auscultation by itself

and a list of references. Each methodology includes at the end a logic chart for synthetization purpose.

In step 1, we try to identify in the structure records all the useful and necessary elements to be able to make a good diagnosis; a preliminary analysis of the hazard can be made.

In step 2, we continue the preliminary analysis of the hazard, in order to specify the areas where the auscultation methodology will be applied.

It is at step 3 that non-destructive techniques, samples of materials for laboratory analyzes, tests carried out directly on the structure, or a combination of these three types of techniques are applied. It is also at this step that we give an order of intervention among these three types of auscultation, this order being able to be a function of the results found during the course of this step.

Depending on the results of the various examinations, measurements and analyzes, a diagnosis and if possible a prognosis are given on the state or the structure disease. In addition, recommendations can be made on the specific management of the structure (enhanced surveillance, safety monitoring, safeguard measures, etc.) and possible solutions for repair.

5.2 List of methodologies available

Up today, ten diagnostic methodologies are on the internet site:

- Diagnosis of corrosion of reinforced concrete (D1-1)
- Diagnosis of frost resistance of concrete (D1-2)
- Evaluation of compression strength of concrete on site (D1-7)
- Detection and localization of passive or active reinforcement in concrete (E2-1)
- Diagnosis of external prestressing protected by cement grout in contact with reinforcements (E2-4)
- Evaluation of the tension in a prestressing tendon (E2-5)
- Evaluation of the bending moment deficit of a prestressed concrete cracked bridge (E2-6)
- Analysis of the behaviour of steel-concrete composite bridge cross-section (E3-1)
- Evaluation of the fatigue life of a metallic structure (E3-2)
- Analysis of the behaviour of the assemblies of a metallic structure (E3-3)

Twenty six other methodologies have been identified, and about a dozen are well on the way to completion and edition.

5.3 Example of methodology

In order to illustrate a diagnostic methodology, we are going to present “the evaluation of the tension in a prestressing tendon”.

5.3.1 Context

Measuring the tension of tendons is generally undertaken to ensure the durability of prestressed concrete structures that are more than 25 years old. Such recognitions are indeed desirable because the loss of prestressing is not always accompanied by visible effects. Nevertheless, in view of the cost of the repairs, the bridge manager must have precise information to define a repair program sufficiently early.

The situation is analyzed according to:

- the nature of the prestress: internal or external;
- the nature of the product used for the injections: cement grout or flexible product (wax or grease);
- the accessibility of anchor heads.

5.3.2 An alysis of the records

Several important information must be gathered during this analysis:

- the age of the structure
- the conditions of access to the tendons: tendon layouts, tendon depth within the concrete, nature of the ducts, method of injection used and results of the tests made during construction;
- the type of tendon to be tested: parallel wire tendon, sigma-oval wires of the KA system, strands, stranded cable of the CO2 kit, etc. ;
- the diameter of the wires or strands as well as the grade of the steel used;
- the anchoring process: buttoned wires, STUP system, wedges anchoring, etc. ;
- the values recorded on the tensioning sheets (when they can be found).

5.3.3 Detailed inspection

It allows to examine the apparent condition of the prestressing tendons, to check the coherence of the plans, to detect possible problems of installation of the prestress which could have taken place during the construction, to take the necessary dimensions, to help position windows, etc.

5.3.4 Auscultation process

It happens exceptionally that the anchoring head of a prestressing tendon is designed to allow the regular monitoring of the tension by weighing with a hollow jack (case of the injection by a flexible product). To do this, it is necessary to have a sufficient length of tendon beyond the anchorage to be able to fix, either directly the jack or an extension of tendon before installing the jack; this supposes to have planned to perform this type of measurement, at the time of construction of the structure.

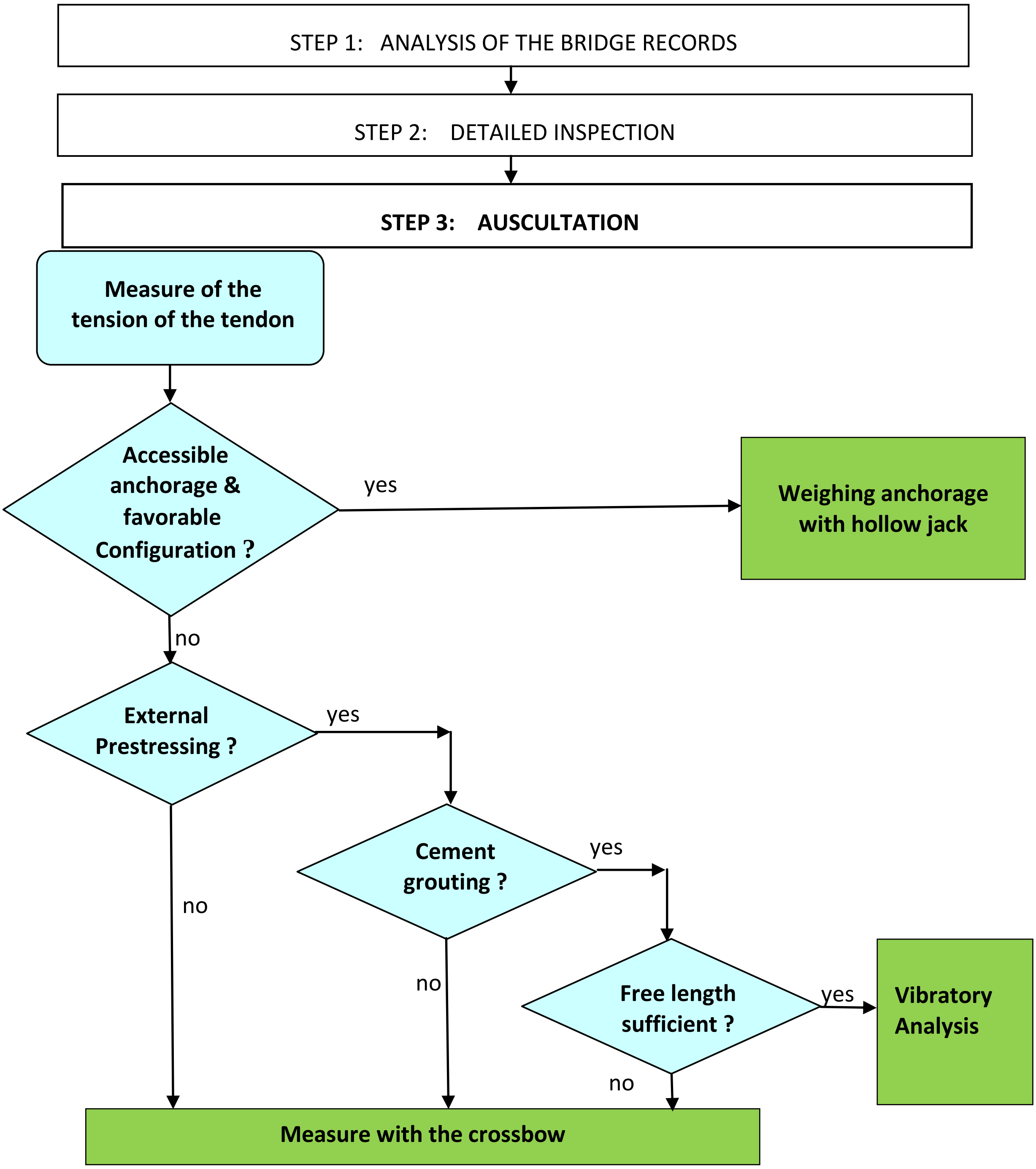

Figure 2: Flowchart for the the evaluation of the tension in a prestressing tendon

In the case of external prestressing injected with cement grout, the tension of a tendon can be measured by vibratory analysis. Indeed, the spectral analysis of the response of a tendon to a shock or sustained oscillations highlights the frequency of the first eigen modes. Assuming that the first eigen modes of the tendon are bending modes, we can rely on the theoretical expression of the natural frequency, which involves the tension of the tendon. The measurement of the tension of the external tendons by vibratory analysis, when it is possible, is rather inexpensive and gives immediate results; it assumes that the tendons are injected with cement grout and have a free length of at least eight meters. The presence of wax or grease, or the total absence of injection product in the duct, prevents the application of this type of methods.

In the case of the internal prestressing, and in the case of the external prestressing injected by a flexible product or in the absence of a “grip” on the tendon at the anchorages, the measurement of the residual tension can be carried out only by using the so-called "crossbow" method. This method consists of exerting a deflection of the tendon, then to draw the characteristic curve “transverse effort versus measured sag”. The theory of elasticity shows that the analysis of this curve makes it possible to assess the tension of the tendon. Naturally, in order to apply this method, it is necessary to release the wires or the strands from the concrete, the sheath and the grout. It will be necessary, in these cases, to make openings in the structure from a facing in order to create a “window” of sufficient size to reach several tendons through the same opening.

In addition to the losses conventionally evaluated during the construction of the structures, the tension of the tendons is a quantity likely to vary from one end to the other of a tendon, as a result of the lengths of re-anchoring and more generally interactions between wires, strands, grout, duct and concrete. Poor quality of grouting can in particular introduce significant tension differences between two points (not necessarily very far apart) of the same tendon. Weighing gives tension to the anchor; the vibratory method gives, by nature, a measurement of the average tension between two deviators, two anti-vibratory devices or two anchoring blocks; finally, the crossbow method gives a local measure of the tension of the tendon.

Finally, it is recommended to compare the results of the measurements with the theoretical tensions of the structure records or with a recalculation taking into account the assumptions of tension and losses existing at the time of construction.

5.3.5 Flowchart

A flowchart (Figure 2) visualizing sequentially and logically the actions to be taken and the decisions to be made to evaluate the tension is given as a guidance.

6. Conclusions

This interactive guide is intended to be used in the case of investigations to be conducted on structures for the diagnosis of a pathology and its prognosis of evolution. It aims to be simple to use, educational and didactic. It also aims at incorporating new methods as they develop and are validated on bridges, in order to make it a living guide. It is a collective work necessitating a good organization in order to manage at least sixty authors.

The guide may be found at the following address:

http://www.ifsttar.fr/collections/CahiersInteractifs/CII1/index.html

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