



Extended abstract

**Catalogue of diagnosis techniques ins structural elements
of current buildings**

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1 Introduction

Nowadays, from both economic and sustainability point of view, it is consensual to extend buildings lifespan as long as its natural physical degradation allows it. Therefore, those infrastructure maintenance and rehabilitation grow even more value regarding its life cycle analysis. It is also generally known that, both buildings and their infrastructure, due to the advancing age, lack of maintenance or natural and accidental causes, will degrade with the appearance of consequent anomalies. Thus, the diagnosis of anomalies affecting currents buildings, takes a role of great importance, particularly when treating structural element's anomalies. These kind of anomalies may jeopardize the structural safety of a building and its efficient operation, and, therefore, it is important to provide technical professionals in the field of Civil Engineering, specific, appropriate and effective tools which could contribute to the efficient diagnosis of such anomalies. It is thus essential that technicians who are engaged in this type of diagnosis may have a deeper and systematized knowledge about the various existing techniques and tests to diagnose relevant cases.

This dissertation aims thereby, to express a contribution in the field of construction, to the lack of information on diagnostic techniques in structural elements of current buildings. Aiming at this objective, this paper proposes a model of diagnostic data sheets, which organizes the cross technical information to the various diagnostic techniques and existing tests. Consequently, it is possible to draw up a catalog in order to identify, organize and disseminate diagnostic techniques for buildings to be renovated, focusing on those whose application refers to structural elements of buildings.

Theoretically, to make a diagnosis corresponds to operate a construction pattern of behavior in which the links between causes and effects are well established. For the rehabilitation of the building elements to consider it is necessary to assess the type and level of deterioration and its causes and consequences, trying if possible to prevent the progression of anomalies based on this information. Often this is not the case and the urgency in the face of anomalies leads to depart for a misfit intervention, since symptoms are conceal and may even exacerbate the problems. This assessment is made by using a wide range of anomalies diagnostic techniques which are a fundamental tool in the choice of solutions to be used by technical engineering and architecture (Costa, 2006).

In an attempt to improve the process of systematization of the various techniques, it would be useful to draw up and propose a model statement for a given diagnostic technique, which contains the various characteristics of its use, including its operating principles and application areas, so the various existing diagnostic techniques can be analyzed and compared.

2 Pathology and diagnosis of current buildings

2.1 Constitution and defects of current buildings

Like the previous, Rodrigues, *et al.*, (2007) also states that the service time interval, the concept of "new building" also includes some constructive characteristic and specific promotional initiative. In other words, there is the near absence of constructive innovation using repeatedly constructive technology based on a structural system built reinforced concrete complemented by masonry panels without structural functions.

The current buildings built with reinforced concrete relate to buildings that fit a time that can be characterized by a marked dispersion in the variety of buildings constructed both in height, size, implantation, and in terms of structural solutions. These buildings already account for the genesis and implementation of the regulations in terms of reinforced concrete and construction. Due to the increase in the height of recent buildings in relation to old buildings, also increases the requirements regarding the strength against seismic action, therefore more rigid vertical elements begin to appear, such as boxes of stairs and elevators. From a structural point of view, the presence of associations of resistant frames and walls in one or two directions, creating the so-called composite structures can still be checked in the buildings on the time period in question.

It is also noteworthy, the emergence of various forms of paving going from solid slabs to the prefabricated joists or ribbed for all of them in one or both directions. With regard to the contact with the outside, the built considered recent shows some differences in relation to buildings considered old, and the first ones feature larger openings for windows, and several floors at the ground floor with almost no masonry. The outer walls generally remain double brick masonry, although in some cases it already can be seen heavy pre manufacture of walls attached to the main structure.

In one general point of view, the deterioration process of a building, is characterized by the causes for the degradation (which can be natural aging or errors associated with the different phases of the construction process responsible for defects), the outer degradation agents and the symptoms of this process (anomalies), which can progress to the rupture (functional and / or physical), affecting performance (Flores-Colen, 2008).

Therefore, when we are faced with structural anomalies, the implementation of a careful diagnosis, it is essential in the search for a solution that will lead to trouble shooting (Aguiar *et al.*, 2006).

With regard to the anomalies of reinforced concrete structures, Córias (2006) stated that these are usually related to lack of construction or design problems, structural changes and deterioration. The authors also add that the existence of anomalies in buildings of reinforced concrete, is typically seen in service situation by cracking with different orientations, excessive deformation, located crushing in the concrete or armor corrosion or breakdown surfaces due to chemical or physical attacks.

According Aguiar *et al.* (2006), anomalous situations in reinforced concrete structures are manifested mainly in the usage phase, by the occurrence of:

- Cracking with different direction;
- Excessive deformations, usually in floors;
- Corrosion of reinforcement bars or disintegration on the surfaces by chemical or physical attack.

2.2 Diagnosis techniques for structural elements

When performing an inspection of a building, it is important to check, sort and record all the anomalies detected in all parts of the building. So for its inspection to be carried out in a careful manner, it is desirable to have different phases in the development of a diagnosis of anomalies for a proper study of the same. (Carrio *et al.*, 2003)

As such, the testing techniques *in situ* can be classified in terms of (adapted from Ferreira, 2010 citing Colen-Flores *et al.*, 2006):

- Level of destruction they cause (destructive, semi-destructive and non-destructive);
- Principles on which they are based on (mechanical, electrical, magnetic, electromagnetic, electrochemical, ultra - sonic, radioactive, sensory, thermal, chemical, electrochemical, etc.);
- Type of results (properties being considered):

Non-destructive tests are generally defined as being not detrimental to the performance of the test element or member when and when applied to concrete, are considered included the methods that cause surface damage perfectly positioned (Nepomuceno, 1999), which the last ones may be termed partially destructive or semi-destructive testing. Finally, as designated, the *in situ* non-destructive diagnosis, do not cause any damage to the analyzed structures. In general, the *in situ* techniques as well as being characterized by non-existence or reduced destructive side, allow an indirect qualitative or quantitative assessment of the most significant features, instead of laboratory tests, which are always slightly destructive (conducted on samples) but can achieve direct quantitative results (Ferreira, 2010 citing Veiga *et al.*, 2004).

2.2.1 Sensorial perception techniques

Diagnostic techniques concerning this group are simple techniques that use little technological means, where the operator uses the own senses to evaluate the situations in analysis, such as visual inspection, and may resort to devices that amplify them. The sensory perception techniques are inherently non-destructive since the opening of cracks or holes in the building in question are not involve.

2.2.2 Mechanical action techniques

This group of techniques involves the application of a mechanical action to the construction element under consideration, which can be either a construction element as a structural element. This mechanical action can be performed via mechanical, electrical, hydraulic or electromechanical or even by removing parts of the element. The tests in this group may have a non-destructive nature, reductively destructive or moderately destructive (Cóias 2006).

2.2.3 Elastic wave propagation techniques

In this type of diagnostic techniques, the tests are based on the detection, measurement or analysis of the vibrations caused on buildings or construction elements by evaluating the propagation of elastic waves (Cóias 2006).

2.2.4 Vibration detection and analysis techniques

The tests regarding this group, are based on monitoring and analysis of structures vibrations subjected to dynamic actions. It enables to obtain data on the characteristics, performance and the presence of any anomalies in buildings under review (Cóias 2006).

2.2.5 Chemical reactions and electrochemical techniques

This group of tests includes diagnostic techniques from two different natures. The chemical nature of techniques aim the study of chemical reactions that occur in the materials under study, regarding this dissertation the reinforced concrete, while in the other tests type are observed electrochemical nature of phenomena occurring in construction elements, spontaneously or as a result of introduced disturbances. With regard to the chemical nature techniques, certain reagents are used which when in contact with certain materials, enable their identification or characterization or their chemical equilibrium (Cóias 2006).

2.2.6 Electromagnetic radiation propagation techniques

These techniques are based on measuring the variation of the radiation on the surface of an element. These kind of tests are governed by the principle that the entire surface emits energy in the form of electromagnetic energy.

2.2.7 Electric and magnetic effects techniques

In the tests developed in this group, is taken advantage of the modifications locally induced in magnetic fields for certain building or its parts. The essays in this group, are inherently nondestructive.

2.2.8 Hydrodynamic techniques

These techniques are used to analyze, in general, the way in which the water enters and moves within the building materials obeying processes such as absorption, capillary effect and permeability associated with pressure differences (Cóias, 2006; Abreu , 2013; Ferreira, 2010).

2.2.9 Monitoring techniques

Regarding the techniques which represent this group, these cannot be considered as tests, but monitoring techniques during the construction time aiming to determine quantities or building behavior characteristics of its elements (Cóias 2006).

3 Design of a model sheet of diagnosis techniques

The proposed model for diagnostic techniques sheet presented in this thesis, was based on the model proposed by Abreu (2013) and Machado (2014), with some changes to the proposed fields, referring in this way for a model sheet for technical and tests applicable to structural building elements streams.

In developing the sheet framework, it was held as main objective, condensation and systematization of the most relevant information concerning diagnostic techniques to be used in structural elements. Thus, each sheet is divided into two pages allowing an easy and more complete query information essential to the operation of the diagnostic technique in question.

The various fields and respective parameters for each technique are arranged in a table, which allows a more organized and detailed information, all ensuring that the information content is visible.

DESIGNATION OF THE DIAGNOSIS TECHNIQUE		Ref.^a
<u>TECHNIQUE'S DESTRUCTIVE LEVEL:</u> <input type="checkbox"/> Destructive <input type="checkbox"/> Semi-destructive <input type="checkbox"/> Non-destructive	<u>ELEMENTS TYPE:</u> <input type="checkbox"/> Structural elements <input type="checkbox"/> Non structural elements	<input type="checkbox"/> <i>In situ</i> <input type="checkbox"/> Laboratory
<u>STRUCTURAL ELEMENTS IN WHICH CAN BE USED:</u> <input type="checkbox"/> Pilars <input type="checkbox"/> Beams <input type="checkbox"/> Slabs <input type="checkbox"/> Resistent walls <input type="checkbox"/> Foundations		
<u>USED PRINCIPLE:</u> <input type="checkbox"/> Sensorial perception <input type="checkbox"/> Electromagnetic propagation <input type="checkbox"/> Mechanical action <input type="checkbox"/> Electric and magnetic effects <input type="checkbox"/> Elastic waves propagation <input type="checkbox"/> Hydrodynamic <input type="checkbox"/> Vibrations detection and analysis <input type="checkbox"/> Higrótermica <input type="checkbox"/> Chemical and electrochemical <input type="checkbox"/> Monitoring		
<u>DESCRIPTION:</u> <p>In this field is presented, in a synthetic way, the diagnostic technique in analysis, where the type of test is indicated and where is made a short introduction to the method. It may contain information regarding the phase of the lifespan of the building on which the method is applied, whenever necessary.</p>	<u>EQUIPMENT/ NECESSARY MATERIAL:</u> <p>This field is used primarily to list and illustrate the equipment and materials required for the application of the technique in question, such as machinery and equipment, mechanical appliances, among others. Are illustrated in the form of photographs or diagrams and serve to a better perception the application of the technique.</p>	
<u>VANTAGES:</u> <p>As the name implies, this field is referred to the major advantages of the technique in question. It is an important field that provides useful information on the virtues of the technique, which allows the user of the catalogue a base of comparison of the various techniques.</p>	<u>LIMITATIONS:</u> <p>Contrary to the left field, in this field are the main disadvantages of the technique in analysis. It is an important field that provides useful information on the limitations of the technique, which allows the user of the catalogue a basis of comparison between the various techniques.</p>	
Ref. ^a .	PRINCIPLE USED	

<p><u>TEST COST:</u></p> <p><input type="checkbox"/> Economic <input type="checkbox"/> Medium <input type="checkbox"/> Expensive</p>	<p><u>NORMATIVE DOCUMENTS:</u></p>												
<p><u>TEST DIFFICULTY:</u></p> <p><input type="checkbox"/> Low <input type="checkbox"/> Medium <input type="checkbox"/> High</p>	<table border="1"> <thead> <tr> <th data-bbox="788 253 887 297">Ref.^a</th> <th data-bbox="887 253 1299 297">Descrição</th> <th data-bbox="1299 253 1391 297">Ano</th> </tr> </thead> <tbody> <tr> <td data-bbox="788 297 887 344"></td> <td data-bbox="887 297 1299 344"></td> <td data-bbox="1299 297 1391 344"></td> </tr> <tr> <td data-bbox="788 344 887 392"></td> <td data-bbox="887 344 1299 392"></td> <td data-bbox="1299 344 1391 392"></td> </tr> <tr> <td data-bbox="788 392 887 439"></td> <td data-bbox="887 392 1299 439"></td> <td data-bbox="1299 392 1391 439"></td> </tr> </tbody> </table>	Ref. ^a	Descrição	Ano									
Ref. ^a	Descrição	Ano											
<p><u>UNCERTAINTY:</u></p> <p>In this field, are set out certain conditions and parameters, which must be taken into account, and that influence the test results</p>													
<p><u>TEST PROCEDURE</u></p> <p>In this field relating to the testing procedure, such as the name indicates, is explained in numerated bullets, all the following procedure to properly perform the test corresponding to the technique in analysis. Procedures were removed of books, technical documents and test sheets or studies of any previous tests.</p>	<p><u>REFERENCE OR ORIENTATES VALUES:</u></p> <p>The reference values are derived from reference documents or values obtained through studies, papers or reports of previous tests and serve as a good basis of information for the user, who can consult them effectively during or after the test in question, in order to infer the validity of the results obtained with the test performed or even to compare values.</p>												
<p><u>RESULTS EXPRESSION:</u></p> <p>This field corresponds to the space where the test results are presented, both numerical results, either in the form of graphics or images. Results can be obtained by the equipment, readings performed by experts, among others.</p>	<p><u>RESULTS INTREPRETATION:</u></p> <p>The results are in this field analyzed and is made a study, with the objective to conclude about the values obtained during the test and predict the diagnosis of the element or material to which the technique was used.</p>												
<p>DESIGNATION OF THE DIAGNOSIS TECHNIQUE</p>													

4 Catalogue of diagnosis techniques

The catalogue of diagnosis techniques for non-structural elements includes a general index, a collection of sheets organized according to the principle of use and the respective bibliography. The catalogue is also accompanied by an illustration showing the various non-structural constructive elements indicated in the sheets.

The catalogue consists in 17 sheets organized according to the respective principles of use (sensorial perception, mechanical action, propagation of electromagnetic radiation, chemical reaction, electric, hydrodynamic and hygrothermal), to provide a quick and expeditious consultation, having been used to encoding illustrated in the Table 1.

Table 1 - Summary of diagnostic techniques sheets developed

PRINCIPLE USED	STRUCTURAL ELEMENTS TECHNIQUES
Sensorial perception techniques (TPS)	1 TPS Boroscopic observation
	2 TPS Monitoring of cracking and cracks
	3 TPS Measurement of displacements in joints and cracks
Mechanical action techniques (TAM)	4 TAM Rebound test – Schmidt hammer
	5 TAM Extraction of concrete cores
	6. TAM Implementation of static load tests of short structures
Elastic wave propagation techniques (TPOE)	7 TPOE Ultrasonic testing on concrete
	8 TPOE Evaluation of the integrity of structural elements by impact-echo method
Chemical reactions and electrochemical techniques (TRQE)	9 TRQE Polarization resistance - evaluation of reinforcement corrosion rate
	10 TRQE The carbonation depth review - Phenolphthalein
	11 TRQE Measurement technique of electrical potential - detection of active reinforcement corrosion
	12 TRQE Determination of the chloride content of concrete
Electromagnetic radiation propagation techniques (TPRE)	13 TRQE Concrete resistivity measurement - risk assessment of active reinforcement corrosion
	14 TPRE Thermographic test
Electric and magnetic effects techniques (TEEM)	15 TEEM Detection of reinforced bars and evaluation of its diameter and coating
	16 TEEM Measuring structures inclinations - inclinometer
Hydrodynamic techniques (THd)	17 THd Figg Method - Evaluation of Concrete apparent permeability to air and water

5 Conclusions

Regarding to current buildings, it was concluded that these have building components of different materials, which itself is a weakness with regard to resistance capabilities of those different materials. This fact triggers a set of specific anomalies, which are caused by the joining of materials with different capabilities and deformability of hygrothermal characteristics, which arise mainly by inadequate design / project or for any shortcomings in construction techniques performed;

In preparing the catalog, the inspection techniques researched and discussed in this work, were grouped into chapters taking into account the operating principle on which they rely in particular techniques of sensory perception, mechanical action techniques, propagation techniques of elastic waves , detection techniques and analysis of vibrations, techniques of chemical and electrochemical reactions, electromagnetic radiation propagation techniques, techniques of electric and magnetic effects, hydrodynamic techniques, hygrothermal techniques, monitoring techniques.

6 Bibliographic references

ABREU, D. M. – *Diagnoses techniques used in Civil Engineering*, Master thesis in Civil Engineering. FEUP. Porto, 2013

AGUIAR, J.; CABRITA, A.; Appleton, J.- *Script to support rehabilitation of residential building*.. Lisboa: LNEC, 2006.

CARRIÓ, J. M.; MONTORO, R. B.; BASAGOITI, L. O. - *Directives for a Correct Diagnosis*. 2nd International Symposium on Building Pathology, Durability and Rehabilitation, LNEC. Lisboa, 2003, pp. 163-172

CÓIAS, V. - *Inspections and tests in the rehabilitation of buildings*. Lisboa: IST Press, 2006. ISBN 972-8469-53-5.

CÓIAS, V. RIBEIRO, M. - *Development of cementitious materials for repair and strengthening of concrete structures*. 2nd Meeting on Building Maintenance and Rehabilitation. LNEC, Lisboa, 1994: 609 – 618

COSTA, A. – *The pathologies and structural rehabilitation*. In PATORREB 2006 - 2nd Meeting on Conservation and Building Rehabilitation. Porto: FEUP, 2006, pp. 57-81.

FERREIRA, J. – *Diagnostic techniques in pathology buildings*. Master thesis in Civil Engineering. Porto: FEUP, 2010.

FLORES-COLEN, I. - Performance assessment methodology on the facades of service tower from the perspective of predictive maintenance. Ph. D in Civil Engineering, Instituto Superior Técnico, 2008.

MACHADO, L. – *Diagnostic techniques in non-structural elements of buildings current catalog*. Master thesis in Civil Engineering, IST. Lisboa 2014

PADRÃO, J. - *Technical Inspection and Diagnostic Framework*. Master thesis in Civil Engineering, FEUP. Porto 2004.

RIBEIRO, T., CÓIAS, V. - *“Construdoctor”*: Pre- Diagnosis Service via the Internet. 3rd Meeting on Building Maintenance and Rehabilitation. LNEC, Lisboa, 2003: 1037 – 1046.

RODRIGUES, R.; SILVA, F. – *Statistical analysis of the condition in recent buildings*. In Congresso Construção 2007 - 3.º Congresso Nacional, UC. Coimbra 2007.