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Original Research Article

Modern acoustic techniques for testing concrete structures accessible from one side only

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ABSTRACT

This paper presents nondestructive methodologies for investigating selected geometrical and material imperfections in unilaterally accessible concrete structures by means of modern acoustic techniques. The imperfections include: improper structure thickness, delamination, large air voids and zones of concrete macroheterogeneities. The presentation of the methodologies is preceded by a survey of the literature on the subject. The available knowledge, also contributed by the present author, has been collected and systematized as well as complemented with two new methodologies for determining the depth of cracks. The methodologies have been validated in situ on building structures whereby their practical usefulness has been confirmed.

1. Introduction

Structures made of concrete are, for different reasons and at different times (during both their construction and use), subjected to tests [8,14,15,21,37,40]. The many test methods which can be used for this purpose can be divided into: destructive, semidestructive and nondestructive methods [1,5,9,10,16,25–27]. It is mainly samples taken from a structure, rarer entire members or structures, which are subjected to destructive tests. In the course of semidestructive tests the structure of the material is locally slightly (usually superficially) breached [10,16]. No such breach occurs in the case of nondestructive tests and the latter can be used to test large surface areas to a substantial depth. Moreover, the measurements can be performed repeatedly (as regards both time and place).

This paper presents modern acoustic techniques helpful in detecting and identifying selected geometric and material imperfections in concrete structures accessible from one side only. Imperfections (defects) result in deterioration in the initial or design condition of a member or the entire structure [1]. The following imperfections: improper structure thickness, delamination, large air voids, zones of concrete macroheterogeneities, and cracks are considered.

In the case of newly built structures, often their thickness and its conformance to the design need to be checked for quality acceptance purposes. As regards structures which have been in service for many years, such a need arises when, for example, their design documents are missing and their

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load-bearing capacity must be checked through calculations. In such cases, the thickness of a concrete structure when the latter is in contact with groundwater or dammed water on one of its sides cannot be determined by the conventional drill-through method and so nondestructive techniques must be employed. Examples of such structures are the foundations and walls of underground garages, the structural members of hydro-engineering structures, the walls of tunnels and collectors, in both newly built structures and the ones which have been in service for many years.

As a result of significant errors in the execution of layered concrete structures the material may lose its continuity due to the lack of interlayer bonding [1,10]. This material imperfection, referred to as delamination, results in a reduction in the load-bearing capacity and durability of the structure. For this reason (among others), before the acceptance and final hand-over of large strongly loaded structures, such as garage floorings, tests are carried out to check the interlayer bonding and to detect any delamination. The semi-nondestructive pull-off method is usually used for this purpose, but its effectiveness to a large extent depends on the number of test points. For example, for concrete floorings the standard specifies one test point per 3 m^3 of the tested area. But this is not sufficient if the boundaries of an area in which delaminations may occur are to be precisely determined. Then it is necessary to use a denser grid of test points, which amounts to a substantial breach of the flooring structure.

At places where different structural members are interconnected material imperfections in the form of large air voids, understood as material discontinuities larger than the maximum diameter of the aggregate in the concrete, may arise (usually during casting). These are weak spots (no proper concrete cover on the reinforcement) in the structure. Boreholes can be drilled to locate large air voids, but this is not always effective. One cannot determine the size of an air void in this way, which makes repair difficult. Neither the nondestructive radiological technique can be used to locate such imperfections.

Zones of macroheterogeneities may appear in the unilaterally accessible massive structures of, e.g., hydroelectric power plants and dams. Macroheterogeneities are defined as material discontinuities smaller than the air voids described above. Particularly at the construction stage massive structures are likely to develop defective zones (material imperfections) due to, for example, improper concrete compaction, the use of too coarse aggregate or the insufficient cover of the latter with cement mortar. The concrete in such zones is excessively porous, which under unilateral water pressure combined with, e.g., the operational vibrations of the structure, contributes to cracking through the concrete (the loss of material continuity along the whole cross section) [11].

There is often a need to determine the depth of a crack (understood as a material discontinuity extending along some of the structure's cross section) whose depth and length are significantly larger than its width. Water often leaks through such a crack. Over time the crack may grow larger (as regards its depth, length and width), which may lead to, e.g., a failure condition of the structure. Crack depth is usually determined by drilling a core sample, but in a situation when there is water on the outer side of the structure, exerting pressure on the latter, this method is risky.

Nondestructive acoustic techniques are helpful in the above cases. A classification of the techniques is shown in Fig. 1. The applicability, limitations, advantages and disadvantages of the techniques are presented in [16].

The testing needs indicated above and the relevant nondestructive techniques (used individually or in combination) are matched in Fig. 2.

The person who is about to examine unilaterally accessible concrete structures for geometric and material imperfections must choose a proper technique and equipment and use a proper test methodology enabling the detection and

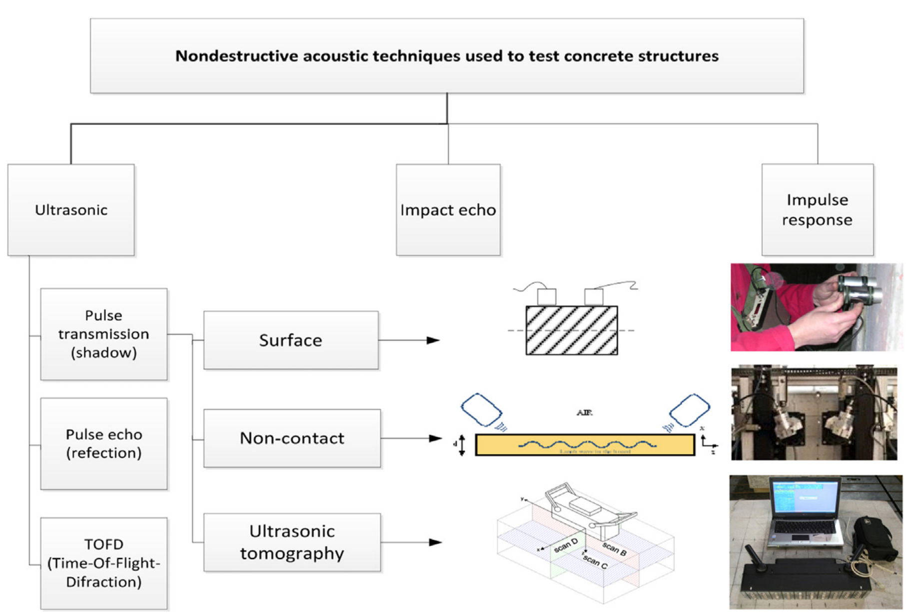

Fig. 1 – Nondestructive acoustic techniques for detecting geometric and material imperfections in concrete structures accessible from one side only.