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Non-destructive identification of pull-off adhesion between concrete layers

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ABSTRACT

This paper presents a methodology for the non-destructive identification of the values of pull-off adhesion between concrete layers in floors on the basis of parameters determined using three non-destructive testing (NDT) methods and artificial neural networks (ANN). The methodology is based on the earlier research by the author. There are three stages in the methodology: stage 1 in which two parameters are determined on the concrete substrate layer surface using the non-destructive 3D laser scanning method and three parameters are determined on the added concrete surface using the acoustic impulse response and impact-echo methods, stage 2 in which an ANN is trained and tested, and stage 3 in which numerical analyses of the results are carried out and the values of pull-off adhesion $f_{c,b}$ are identified. It is shown that the methodology is practicable, as demonstrated by the provided example.

1. Introduction

The durability of concrete structures depends on the proper bond between the added concrete layer and the existing concrete substrate layer [1–5]. The measure of this bond is the value of pull-off adhesion f_b. The latter, in practice determined by the semi-destructive testing (SDT) pull-off method, should amount to less than 0.5 MPa according to [6]. According to [1], in order for the tests to be reliable 1 measurement per 3 m^2 of floor surface should be taken. The check measurement in this method consists in drilling a 50 mm diameter borehole in the added concrete layer of the floor. The sample created in this way is pulled off from the concrete substrate layer, as described in US standard ASTM D 7234 [7] and in European standard EN 12504-3:2006 [6]. The drawback of the pull-off method, particularly in the case of large-surface floors, is that the tested surface is locally damaged in many places and then needs to be repaired. This drawback can be eliminated through the use of non-destructive testing methods (NDT) and artificial neural networks (ANN) [8–23]. Nowadays the number of applications of ANNs in different engineering areas still increases [24–27].

Studies described in [28–32] have shown that it is possible to reliably determine the pull-off adhesion through the use of the three NDT methods: the 3D laser scanning method and the acoustic impulse response and impact-echo methods plus ANN as a tool for correlating the results obtained by means of the above methods. Whereas as shown in [33–35], it is not possible to establish reliable correlations between pull-off adhesion f_b and the individual parameters determined by different NDT methods.

In [36] (similar in its subject to the present paper) a methodology for the non-destructive assessment of the bond between the concrete layers in floors was developed for two cases: 1) delamination occurs (pull-off adhesion f_b amounts to 0) and 2) delamination does not occur, but without the possibility of determining intermediate pull-off adhesion values in the latter case.

The methodology proposed in this paper offers such a possibility. The methodology uses parameters estimated on the concrete substrate layer surface by the latest 3D laser scanning method [37–50] and parameters estimated on the floor surface by the impulse response and impact-echo methods [51–59] and ANN.

It should be explained that since paper [36] no new papers dealing with this problem have been published and therefore no typical survey of literature is presented here.

2. Synthetic description of NDT test methods used

Tables 1–3 present basic information on the latest 3D laser scanning method and the acoustic NDT impulse response and impact-echo methods used in the tests which provided the basis for developing the methodology.

3. Short description of tests providing basis for methodology

As presented in [28–32], the tests providing the basis for the methodology were carried out on two 2500 × 2500 mm model concrete

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Table 1
Synthetic description of 3D laser scanning method [37–50].

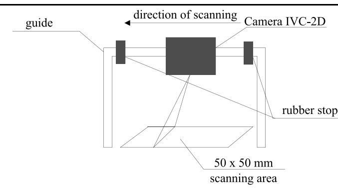
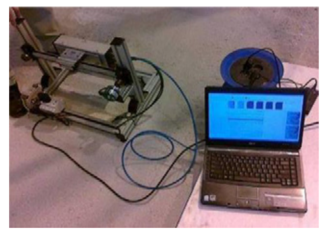
Name and description of method	Schematic and view of test setup	Recorded parameters
1	2	3
The 3D laser scanning method exploits laser triangulation. It consists in measuring the deformations of a line produced by the measuring device's laser beam. A camera driven by a stepper motor is responsible for measuring the distance between the particular points located on the tested surface. Owing to this measurements can be taken in profiles spaced at every 10 μm with a vertical accuracy of 15 μm. Each point is assigned three coordinates describing its position on the tested surface. The size of the measuring field subjected to testing by this method is 50 mm × 50 mm, which corresponds to the field subjected to testing by the pull-off method.	 	Using this method one can determine the values of the 3D roughness parameters specified in standard [49], and analyze surface morphology by means of specialist software. In particular the following are determined: - arithmetical mean height *Sa*, - root mean square height *Sq*, - surface bearing index *Sbi*.

Table 2
Synthetic description of acoustic impulse response method [51–53].

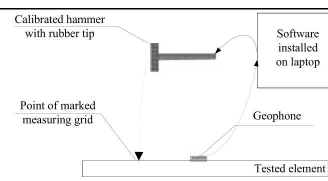
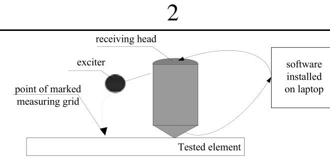
Name and description of method	Schematic and view of test setup	Recorded parameters and exemplary test results
1	2	3
The impulse response method is based on the excitation of the an elastic ultrasonic wave in the tested element by means of a calibrated hammer with a rubber tip. The frequency of the excited wave is in the interval of 1–800 Hz while the excitation range around the test point amounts to about 1000 mm. This method is suitable for the fast searching of large concrete surfaces and enables, among other things, the approximate identification and surface location of delaminations and the assessment of the pull–off adhesion of concrete layers to a depth of about 1500 mm.	 	The values of the following parameters are recorded: – average mobility N_{av}, – stiffness K_d, – mobility slope M_p/N, – average mobility times mobility slope $N_{av} \cdot M_p/N$, – voids index *v*.

Table 3
Synthetic description of acoustic impact-echo method [54–59].

Name and description of method	Schematic of test setup	Recorded parameters and exemplary test results
1	2	3
The impact echo is based on the excitation of a low frequency (1–60 kHz) wave in the tested element by striking its surface with an exciter in the form of a steel ball (with different diameters). Specialist software is used to record the graphic image of the elastic wave propagating in the tested element, in the amplitude–time system, and to transform this image into an amplitude–frequency spectrum by means of the fast Fourier transform. This method is suitable for testing concrete members to estimate the thickness of unilaterally accessible members, the adhesion between layers, delamination, etc.	 	The values of the following parameters are recorded: – transmitting impulse amplitude *A*, – the frequency of ultrasonic wave reflection from the defect (f_D), – the frequency of ultrasonic wave reflection from the bottom (f_T).