The non-destructive method of identifying adhesion between a repair overlay and concrete substrate using artificial intelligence

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Abstract

Concrete elements that are exposed to adverse environmental impacts require some non-structural surface repair after some time. After the removal of the corroded surface layer of concrete, a repair overlay is applied in this place, usually of variable thickness. The effectiveness of such repairs with regards to bonding is assessed in construction practice by measuring the value of pull-off adhesion with the use of the pull-off method. However, the repair overlay in this method is damaged at every tested measuring point. This shortcoming significantly affects the reduction of the number of measuring points, which in turn limits the verification of the effectiveness of repair works. In order to eliminate this disadvantage, a non-destructive evaluation of pull-off adhesion between the repair overlay and the surface of the repaired element was proposed. This method is based on the comprehensive use of several research methods and then followed by "corelating" them with the aid of artificial intelligence. The results and analysis obtained in this field are the subject of the paper.

Keywords: NDT, pull-off adhesion, 3D laser scanning, acoustic methods

1 Introduction

Concrete constructions exposed to adverse environmental influences require non-structural surface repair after some time [1]. Such repair is typically carried out with the use of repair mortar after the removal of the damaged (e.g. corroded) subsurface concrete layer [2]. The removal of the damaged layer is done mechanically, e.g. by milling, shot blasting or grinding [3-4]. The thickness of the removed concrete layer is usually different at different places of the repaired element and depends on the damage of the concrete. After repair, the element becomes a layered element, as its overlay is a repair mortar. An important parameter that provides information about the quality of the conducted repairs is the pull-off adhesion between the repair overlay and the repaired element. The measurement of this adhesion is carried out in construction practice with the use of the pull-off method [5]. The disadvantage of the pull-off method is the damage that occurs at every measuring point, which later requires repair [6]. According to [5-7], in order to limit the probability of damaged areas not being found, there should be one control measure per surface area of no more than 3m². It is then possible to draw a rough "adhesion map" that is used for locating defective areas.

Clarity of a defective area, especially its borders, requires further densification of the grid of measuring points, in which attempts to pull off the repair overlay need to be made. This intensifies the
problem of the disadvantage of the pull-off method, as the number of places requiring repair after
testing increases. For these reasons, the above-mentioned standard requirements are often not
respected in practice, especially in the case of large surface elements. This translates into the
possibility of missing areas with an insufficient value of pull-off adhesion, which will result in
reduced durability of the conducted repair.

Due to the above, it is reasonable to look for a non-destructive testing (NDT) method of evaluating
the pull-off adhesion value between an added repair overlay with variable thickness and a repaired
element that is a substrate for the overlay. For this purpose, the authors have proposed the use of
several NDT methods that are comprehensively applied, namely: the 3D laser scanning method [8-9]
that is used on the surface of the substrate, the hammer acoustic method and impulse response method
[12-13] that are used on the surface of the overlay, the precise surveying method [16] that is applied
on the surface of both layers, and also artificial intelligence in order to "correlate" the results obtained
with these methods [10]. Concrete elements with an added overlay made of repair mortar, which is
used in building practice to repair concrete structures, were tested in laboratory conditions using the
above-mentioned NDT methods. The tests were intended to answer the question of whether the
proposed method would enable satisfactory results to be achieved and whether it could be proposed
for practical use.

2 The conducted experimental tests and numerical analysis

Experimental tests and numerical analysis were carried out in two stages. Experimental tests were
conducted in stage 1, whereas numerical analysis was carried out in stage 2. Two different layered
concrete elements were subjected to the experimental tests. At first, the bottom layer of these elements
(concrete substrates) was made of C30/37 concrete. After 28 days, the surface of one of them was shot
blasted and the surface of the second was partially grinded and left partially untreated. Afterwards, a
grid with 338 measuring points was applied on the surfaces of both elements, and measurements using
the 3D laser scanning method were carried out in order to obtain parameters that describe surface
morphology. Precise surveying method tests were also made at these locations in order to later
determine the thickness of the repair overlay with variable thickness. Subsequently, non-structural
"repair" of these surfaces was performed by applying a repair overlay made of Polymer Cement
Concrete (PCC) mortar with a variable thickness ranging from 2.5 cm to 6 cm. After 28 days, in the
same places as on the surface of the concrete substrate, a grid of measuring points was applied on the
surface of the overlay and tests were conducted using the impact-echo method, impulse response
method and precise surveying method. After that, in order to determine the real values of pull-off
adhesion, tests were carried out at the same measuring points using the pull-off method.

As a result of the experimental tests, values of the following parameters were obtained:
- with the use of the 3D laser scanning method in accordance with ISO 25178 [11]:
  - $Sk$ – core height [mm],
  - $Spk$ – reduced peak height [mm],
  - $Svk$ – reduced dale height [mm],
  - $S10z$ – 10 point height [mm],
  - $S5p$ – 5 point peak height [mm],
  - $S5v$ – 5 point valley height [mm],
  - $Spd$ – density of peaks [1/mm$^2$],
  - $Spc$ – arithmetic mean peak curvature [1/mm$^2$],
  - $Sda$ – closed dale area [mm$^2$],
  - $Sha$ – closed hills area [mm$^2$],
- using the impact-echo method in accordance with ASTM C1383 [12]:
  - $f_T$ – frequency of the sound wave reflection from the bottom of a sample [kHz]
- using the impulse response method in accordance with ASTM C1740 [13]:
  - $N_{av}$ – average mobility [m/s*N],
  - $K_d$ – stiffness [-],
  - $M_p/N$ – mobility slope [-],
  - $v$ – voids index [-]
- using the precise surveying method:
  - $T$ – thickness of the repair overla [cm].

The scheme that illustrates the scope of laboratory tests conducted in stage 1 is presented in Figure 1.
Fig. 1. Scheme that illustrates the scope of the conducted experimental tests (stage 1)
The second stage of the study was conducted based on the results obtained from the experimental tests. This stage involved the carrying out of numerical analysis using artificial intelligence in order to predict the pull-off adhesion value between the repair overlay and the substrate based on parameters obtained using NDT methods. The scheme illustrating the scope of conducted numerical analysis is presented in Figure 2.

Fig. 2. Scheme illustrating the scope of conducted numerical analysis (stage 2)
As shown in Figure 2, the first step during this stage, after loading a file with the data obtained from the experimental tests, was the selection of input parameters for artificial intelligence. The following parameters were chosen for the analysis: Spk, Sk and S10z obtained using the 3D laser scanning method; T obtained using the precise surveying method; \( K_d \), \( v \) obtained using the impulse response method, parameter \( f_T \) obtained using the hammer method, and also the value of the pull-off adhesion \( f_b \) obtained using the pull-off method in order to teach and test the artificial intelligence. Numerical analysis was then conducted in order to select the most useful artificial intelligence tool for such analysis.

It should be noted here that the detailed results of this analysis are presented in papers [14-15]. In paper [14], the artificial neural network with back-propagation error, the Broyden-Fletcher-Goldfarb-Shanno learning algorithm (BFGS) and the number of hidden layer neurons equal to 3 was used for this purpose. Relatively high values of linear correlation coefficient \( R \) equal to 0.844, 0.904 and 0.877 were obtained for learning, testing, and validation processes, respectively. In contrast, in work [15], a method of radial basic function kernel (SVM - RBF) was used, for which relatively high linear correlation coefficients \( R \) equal to 0.841, 0.808 and 0.789 were obtained for teaching, testing and validation, respectively.

As a result of the conducted analysis, an artificial intelligence tool, in the form of an artificial neural network with a selected structure and function of hidden layer activation, was chosen.

3 Use of the proposed method in practice

The use of the proposed NDT method of evaluating the value of the pull-off adhesion between a repair overlay and a concrete substrate seems to be possible in practice. The use of the schemes shown in Figures 1 and 2 is required for this purpose, followed by tests performed on a real element, as shown in Figure 3. Verification of the results obtained using non-destructive tests should be carried out with the use of the pull-off method, which is applied at randomly selected locations.
Fig. 3. Scheme showing the course of action when using the proposed method of non-destructive evaluation of the pull-off adhesion value between a repair overlay and a concrete substrate in practice

4 Summary

The paper shows a method of non-destructive evaluation of the pull-off adhesion between a repair layer with variable thickness and a concrete element that is being repaired. The results of tests that were carried out using artificial intelligence, the 3D laser scanning method, the precise surveying method, the hammer acoustic method and the impulse response method were used for this purpose. Schemes that show the course and scope of required experimental and numerical analysis using artificial intelligence in the form of the selected artificial neural network were also presented. A scheme that presents the possibility of using the proposed method in practice was also proposed.
References