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Non-destructive neural identification of the bond between concrete layers in existing elements

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HIGHLIGHTS

- Pull-off adhesion between concrete layers in existing elements was identified.
- Input data were given by impact-echo and impulse response methods.,
- Real world data of pull-off adhesion were used for building learner models.,
- Gradient descent learning algorithm was applied.,
- The methodology of pull-off adhesion prediction in existing elements was developed.

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ABSTRACT

The paper presents the results regarding the identification of the value of the pull-off adhesion between a concrete added layer with a constant thickness and a substrate concrete layer in existing elements. A method of identification, which is based solely on the use of artificial neural networks (ANNs) and two non-destructive acoustic methods: impact-echo and impulse response on the surface of the added layer, was developed. The methodology of identifying the pull-off adhesion between a concrete added layer and a substrate layer in existing elements was developed and presented in the paper and is useful in construction practice.

1. Introduction

In construction practice it is often necessary to experimentally determine the value of the pull-off adhesion f_b between the concrete added layer and the substrate layer in existing multi-layered elements. This is usually done with the aid of the pull-off method [1–3]. The use of the aforementioned method, however, results in local damage of the added layer in all testing areas, which then require repair [3–11]. Non-destructive methods do not have such a disadvantage [12–25].

On the basis of previous studies authors have developed a methodology for the non-destructive identification of the interlayer bond for newly executed concrete elements with a constant thickness of the added layer. This methodology was based on two parameters of the surface roughness of the substrate layer, evaluated experimentally using the non-destructive optical 3D laser scanning method, and three parameters evaluated experimentally on the surface of the added layer using modern non-destructive testing (NDT) methods: impulse response and impact-echo and also using artificial neural networks (ANNs) [26,27]. ANNs are now being used more frequently by the engineers to solve a whole range of real engineering problems [28–35].

It is clear that in existing concrete elements there is no possibility of carrying out tests of the surface roughness of the substrate layer. It is therefore not possible to adapt previously developed methods and the methodology to identify the interlayer bond in existing elements. This is why laboratory tests were carried out to identify the bond using only two acoustic NDT methods on

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the surface of the added layer: impulse response and impact-echo. The ANN was used to correlate test results obtained using these methods. Results of experimental and numerical analyses are presented in the article.

2. Description of conducted tests

The tests were carried out on a two-layer model concrete element with dimensions of 2500 × 2500 mm with a constant thickness of the added layer equal to 25 mm, as shown in Fig. 1. The added layer was made of C20/25 class concrete with the maximum quartz aggregate grain size equal to 2 mm. It was laid on the substrate layer with a constant thickness of 125 mm made of C30/37 class concrete which was modified with fly ash. In this concrete the maximum broken basalt aggregate grain size was equal to 8 mm.

Fig. 1 shows the scheme of this element, its cross-section through layers and the distribution of testing areas. The grid of the testing areas was applied on the surface of the added layer 500 mm from its edge. The columns of the grid were designated with letters A to H and the rows with numbers from 1 to 16. The number of testing areas was equal to 256.

In order to achieve a broader range of pull-off adhesion f_b between the added layer and the substrate layer, the surface of the substrate layer was divided into two parts denoted by Roman numerals I and II. Each part was prepared differently before the application of the added layer, namely:

- Surface I: prepared by sandblasting,
- Surface II: also sandblasted as in Surface I, but afterwards a bonding agent in the form of concentrate to be diluted with water was applied on it. The surface was then primed 4 h before the laying of the added layer. After this time the added layer was applied on the whole element.

90 days after concreting the added layer, tests using two acoustic NDT methods were carried out on its surface in 256 designated testing areas, which were distributed and designated as shown in Fig. 1. In all these areas the values of the following parameters, obtained using the impulse response method by using s'MASH Impulse Response System by Germann Instruments [36] in accordance with [37–40], were determined:

N_{av} – average mobility,
K_d – dynamic stiffness,
M_p/N – mobility slope,
v – void index,

and the value of the following parameter obtained using the impact-echo method by using DOCter Impact-Echo System by Germann Instruments [41] in accordance with [42–44]:

f_T – frequency of the sound wave reflection from the bottom of a sample.

After finishing the tests using acoustic NDT methods, tests using the pull-off method were conducted in the same testing areas obtaining real values of pull-off adhesion f_b by using automated pull-off tester DY-216 by Proceq [45]. The f_b values were then used as patterns for learning and testing the ANN.

3. Exemplary test results

Table 1 summarizes exemplary several tens of result sets out of 256, including the values of parameters N_{av}, K_d, M_p/N, v and f_T obtained experimentally from the individual testing areas using NDT methods: impulse response and impact-echo, and also parameter f_b obtained with the use of the pull-off method.

4. Preliminary numerical analysis

4.1. Selection of the number of hidden layer neurons of the ANN

Helpful in the estimation of the number of hidden layer neurons of the ANN is a measure of Vapnik-Chervonenkis, marked with the symbol VCdim, which according to [46] should meet the following condition:

$$2\left[\frac{K}{2}\right]N \leqslant VC\dim \leqslant 2N_w(1+\log N_n). \qquad (1)$$

The *VCdim* measure enables the number of hidden layer neurons K, whose minimum number is sufficient to create an ANN that

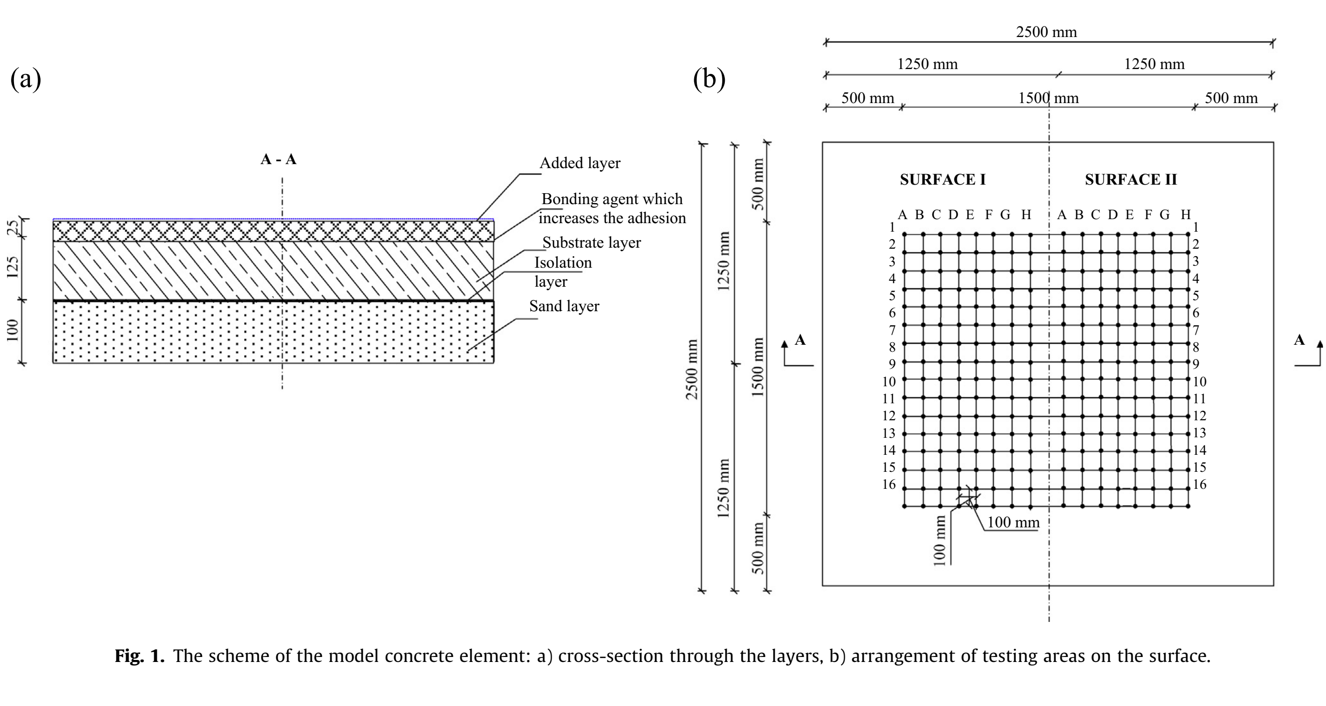

Fig. 1. The scheme of the model concrete element: a) cross-section through the layers, b) arrangement of testing areas on the surface.