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Pull-off adhesion prediction of variable thick overlay to the substrate

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ABSTRACT

Non-destructive identification of the pull-off adhesion of a concrete substrate to an overlay mortar with variable thickness using artificial neural networks (ANNs) is studied in this paper. Selected ANNs with various training algorithms were tested on the basis of the parameter which describes the thickness of the overlay and also the parameters specified experimentally using non-destructive testing (NDT) methods. Real world data collected from experiments of pull-off adhesion were used for building our learner models. The tests were carried out in the same place where tests using NDT methods were performed. Three variant analyses of the possibility of such identification were conducted. The variance was calculated for these testing methods and parameters obtained with their usage, without considering the parameter that describes the thickness of the overlay in this work.

1. Introduction

Recently layered concrete elements become more popular in civil engineering and construction. They usually consist of overlay added to the existing concrete substrate. The proper adhesion between these layers determines its durability. To measure the property of this adhesion, the value of pull-off adhesion f_b between the overlay and the substrate has to be identified using time-consuming and destructive pull-off method [1,2]. According to [2], the value of f_b should not be less than 0.5 MPa for new and 1.5 MPa for repaired elements. Also, one measurement needs to be conducted for a surface of 3 m^2. In practice, this requirement is not commonly obeyed, as the number of measurement points is limited due to the fact that damage arising in the course of tests needs to be each time repaired. Thus, it is necessary to develop a method which is devoid of this shortcoming [3].

In order to develop a universal method of identifying the value of the f_b, tests of a model concrete layered element with linearly variable thickness of the overlay were carried out. Based on the parameters obtained experimentally using non-destructive testing (NDT) methods and the parameter which describes the thickness of the overlay, the artificial neural networks (ANNs) selected for this purpose were taught and tested. This was done in several variants. The variance was calculated for each variant, leaving each time a parameter that describes the thickness of the overlay. Models in the form of the real values of the f_b were used for training the ANNs. These values were obtained experimentally using the pull-off method in the same places in which tests using NDT methods were made.

The remainder of the paper is organized as follows. Section 2 presents compressive literature survey. Section 3 presents the description of research problems with background and data acquisition. Section 4 presents statistical analysis on input variables while Section 5 is the performance evaluation. Section 6 condenses results analysis and verification summarized by conclusions presented in Section 7.

2. Related work

Many researchers show that exist a relationship between parameters characterizing the roughness of the concrete substrate and the f_b of concrete layers [4–9]. In [10] the usefulness of arithmetical mean high *Sa* to the identification of f_b of concrete layers has been presented. Then, in [11] the usefulness of 3D roughness parameters for the evaluation of the f_b of concrete layers using 3D LASER scanning has been evaluated. The texture aspect ratio (*Str*) and the peak material volume (*Vmp*) has been found to be useful for this purpose. In [12] the relation between the values of 3D morphological amplitude parameters *Sq*, *Sku* and *Ssk* and the f_b of the epoxy resin coating has been evaluated. NDT methods, especially the following acoustic methods: impulse response (IR), impact-echo (I-E) and also the ultrasound echo [13–15], were used to assess the f_b. The authors of the above-mentioned research work dealt with f_b without an assessment of its value, each time using a single NDT method.

Up to date, a few of comprehensive application attempts of NDT acoustic methods evaluating of the bond between concrete layers have been undertaken. As can be seen from these studies [16–19], the simultaneous usage of several NDT methods enables a greater efficiency in solving scientific problems, including the assessment of a bond

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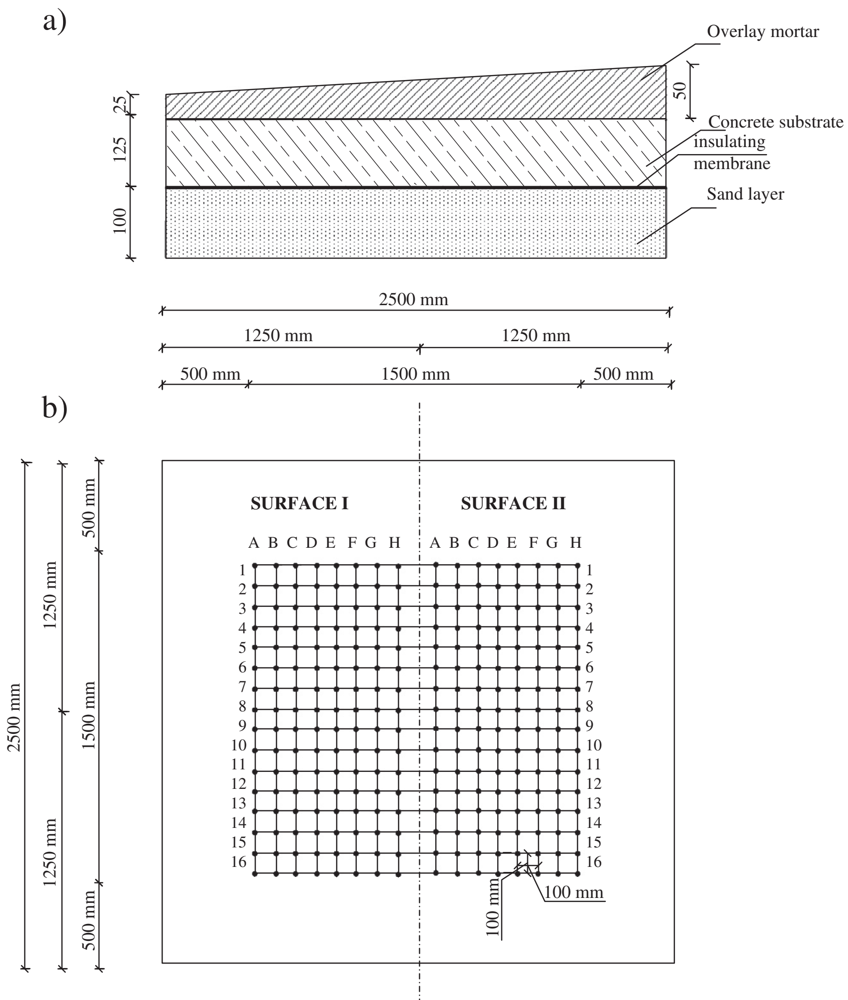

Fig. 1. Sketch of the model concrete element: a) cross section through its layers, b) the division of the surface of the substrate due to the way it is prepared and also test point locations [44].

between layers, to be achieved. The first such attempt is the methodology of the non-destructive evaluation of the bond between concrete layers in floors, which was developed and verified in practice and presented in study [20]. This methodology is only useful for determining the occurrence of delamination (which corresponds to the state where the value of the f_b is equal to 0), or for the lack of delamination. It does not enable the intermediate values of adhesion to be determined, and therefore the value of f_b to be determined non-destructively.

In our previous studies, we have already developed a non-destructive method for identifying the value of the f_b [21–23]. This method has been automated using ANNs. The feed-forward ANN with back-propagation (BP) algorithm and with radial basis function (RBF) were used. A methodology of this identification was also developed using floors as an example [24]. In [25] it has been proved that reliable identification of the value of the f_b between an overlay and an existing concrete substrate in existing elements is possible. However, it applies to the case where the overlay has a constant thickness. Since in construction practice the overlay very often has variable thickness, the developed method is not universal. It cannot be used in the case of concrete elements under renovation, as the thickness of the overlay in various locations is usually different and adapted to the existing concrete substrate which has been prepared to be repaired. The developed method is also not applicable in existing concrete multilayered elements due to the lack of possibility of obtaining values of surface roughness parameters of the substrate.

3. Problem statements

3.1. Factors influencing the f_b

According to [26–27], the most important factors affecting the level of the f_b include the compressive strength of concrete substrate and also its temperature, moisture movement and humidity [28,29]. According to [30–35], the physical properties of joined materials such as viscosity, wettability, bonding shrinkage, thermal expansion and the modulus of elasticity are also important. In contrast, the porosity of the substrate and the occurrence of microcracking have the highest impact on the level of the f_b [36]. The surface morphology and texture of the substrate has a significant impact on this value [37–39]. Mechanical adhesion, and therefore the bond between layers, depends mainly on an appropriate way of preparing the surface of the substrate [40–43].

3.2. Background

As mentioned in [44], in order to develop a universal method of identifying the value of the f_b of the overlay mortar with linearly variable thickness to the substrate, tests of the model concrete element with dimensions of 2500 × 2500 mm were carried out. The size of the element guaranteed the acquisition of the necessary number of datasets needed to create a sufficiently large database. Taking into account the diameters of the borehole of 50 mm applied in pull-off method, a grid of test points was taken in a spacing of 100 mm. Therefore, assuming a grid of test points with dimensions of 100 × 100 mm, we obtain a test