Testing interlayer pull-off adhesion in concrete floors by means of nondestructive acoustic method

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Abstract

The durability of concrete floors is to a large extent depends on the pull-off adhesion of the topping to the base. When making or repairing concrete floors it is highly important to properly prepare the interlayer bonding surface. The measure of the interlayer bond is the pull-off adhesion value. The latter is determined by seminondestructive pull-off tests. In this research the nondestructive acoustic impulse response method and the seminondestructive pull-off method were employed to test the interlayer pull-off adhesion in concrete floor models. The surface of the base layer in the latter had been prepared in four ways. The aim of the investigations was to find out whether it is possible to determine reliable dependencies between the particular acoustic parameters obtained from impulse response tests and the pull-off adhesion obtained from seminondestructive pull-off tests for different ways of preparing the surface of the concrete base.

Key words: concrete floors, interlayer bond, nondestructive tests, impulse response, pull-off

1. Introduction

In concrete floors there may occur all kinds of construction defects and damage. No adhesion at the topping/base interface is one of such defects. The degree of bonding between the base and the topping depends on the proper preparation of the base surface. It is obvious that the durability of concrete floors greatly depends on this bond.

Pull-off adhesion $f_{bo}$, in practice determined by the seminondestructive pull-off method, is a measure of the interlayer bond. It should be noted that the effectiveness of the pull-off method depends on the number of cores drilled. According to [1], one core per $3 \text{ m}^2$ of floor should be drilled. Such a high density of cores drilled has a significant adverse effect on the condition of the tested floor surface. After the tests the areas of the floor damaged by drilling have to be repaired, which is a major drawback of the pull-off method.

It has been demonstrated that the impulse response method is effective in locating non-adhesion areas at the interlayer contact [2], but it is not known whether it is suitable for determining pull-off force $f_{bo}$. It could be applied for this purpose if the dependences between pull-off adhesion $f_{bo}$, determined by the seminondestructive pull-off method, and the values of the particular parameters registered using the nondestructive impulse response method were reliably known. Then it would be possible to practically determine pull-off adhesion $f_{bo}$ in any measuring point without harming the surface of the tested concrete floor. The present research was undertaken to determine the above dependencies.

2. Brief description of test methods

The nondestructive impulse response method consists in the generation of an elastic wave in the tested element by means of calibrated hammer tipped with rubber. The elastic wave frequency is in a range of 1-800 Hz. The tested element is hit with the hammer in selected measuring points. The signal of the elastic wave propagating in the element is registered by a geophone and simultaneously amplified by an amplifier. The registered signals are then processed using a dedicated software installed on a laptop (fig. 1a). Such parameters as: average mobility $N_{av}$, stiffness $K_d$, mobility slope $M_p/N$, mobility times mobility slope $N_{av}M_p$ and voids index $v$ are registered to locate non-adhesion areas in a concrete floor [2]. The impulse response method is described in detail in [3-5].
In the case of the seminondestructive pull-off method, interlayer adhesion is determined through the measurement of the pulling off force by means of an actuator with a digital or dial pressure gauge. In order to test a concrete floor one must drill cores 50 mm in diameter and pull them off the base. The pulling off force value, displayed or indicated by the pressure gauge, is used to calculate pull-off adhesion $f_b$ [1]. Figure 1b shows the equipment used for testing by this method.

3. Range of tests

Tests were carried out on two 2500×2500 mm concrete floor models consisting of a 25 mm thick topping on a 125 mm thick base. The topping was made of C20/25 grade cement mortar. The base was made of grade C30/37 concrete and aggregate with a maximum grading of 8 mm. Prior to testing the elements had been stored at a temperature of 20°C±5°C in a laboratory. The base was laid on a 100 layer of sand. Impulse response and pull-off tests were carried out after the topping had cured for 90 days.

The aim of the tests was to find out if reliable dependencies between the particular impulse response parameters and pull-off adhesion could be established.

Four ways (denoted with Roman numerals from I to IV) of preparing the surface of the base were adopted (fig. 2). After the topping of the concrete floor model had been appropriately marked, 1500×1500 mm test areas were demarcated and a grid of points spaced at every 100 mm was marked on each of them, leaving a minimum margin of 500 mm from the edge. In total, 128 measuring points were marked. The columns and the rows were denoted with respectively letters from A to H and numbers from 1 to 16.

The nondestructive impulse response tests consisted in exciting an elastic wave in each point of the measuring grid by means of the calibrated hammer (fig. 3a). As a result, the characteristic acoustic parameters $N_{av}$, $K_d$ and $M_d/N$ (defined in fig. 2) were determined in each of the points.
The pull-off tests consisted in determining the adhesion of the topping to the base through the measurement of the pulling off force by means of the actuator with a digital pressure gauge. For this purpose cores 50 mm in diameter were drilled in the topping in the same points in which previously the impulse response tests had been carried out, and pulled off from the base (fig. 3 b).

![Fig. 2. Ways of preparing concrete base surface and nondestructive method and seminondestructive method with parameters used.](image)

![Fig. 3. a) testing by nondestructive impulse response method, b) cores drilled in topping.](image)
5. Test results and their analysis

Selected statistical characteristics of the parameters determined by the nondestructive impulse response method and by the seminondestructive pull-off method are shown in table 1. The impulse response method yielded average mobility $N_{av}$ ranging from 31.145 to 119.988 m/s·N for surface I, from 57.211 to 783.872 m/s·N for surface II, from 54.805 to 783.872 m/s·N for surface III and from 39.467 to 99.218 m/s·N for surface IV. The highest values of average mobility $N_{av}$ were obtained for surface II and the lowest for surface I.

Stiffness $K_d$ ranged from 0.004 to 0.119 for surface I, from 0.002 to 0.116 for surface II, from 0.003 to 0.115 for surface III and from 0.001 to 0.075 for surface IV. The highest values of stiffness $K_d$ were obtained for surface I and the lowest for surface IV.

Mobility slope $M_p/N$ ranged from 0.011 to 3.997 for surface I, from 0.036 to 9.722 for surface II, from 0.603 to 12.777 for surface III and from 0.098 to 3.217 for surface IV. The highest values of mobility slope $M_p/N$ were obtained for surface III and the lowest for surface IV.

The seminondestructive pull-off method yielded pull-off adhesion $f_b$ ranging from 0.662 to 1.299 MPa for surface I, from 0.306 to 0.688 MPa for surface II, from 0.204 to 0.891 MPa for surface III and from 0.306 to 1.274 MPa for surface IV. The highest average values of pull-off adhesion $f_b$ were obtained for surface I and the lowest for surface II.

Table 1. Selected statistical characteristics of parameters determined by nondestructive impulse response method and seminondestructive pull-off method.

<table>
<thead>
<tr>
<th>Way of preparing surface of base</th>
<th>Parameter name</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average mobility $N_{av}$</td>
<td>69.049</td>
<td>361.573</td>
<td>245.078</td>
<td>72.807</td>
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<tr>
<td></td>
<td>Standard deviation</td>
<td>20.701</td>
<td>297.336</td>
<td>207.726</td>
<td>14.481</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>31.145</td>
<td>57.211</td>
<td>54.805</td>
<td>39.467</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>119.988</td>
<td>973.371</td>
<td>783.872</td>
<td>99.218</td>
</tr>
<tr>
<td></td>
<td>Stiffness $K_d$</td>
<td>0.041</td>
<td>0.032</td>
<td>0.030</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>0.034</td>
<td>0.030</td>
<td>0.033</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.004</td>
<td>0.002</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.119</td>
<td>0.116</td>
<td>0.115</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>Mobility slope $M_p/N$</td>
<td>1.779</td>
<td>2.716</td>
<td>4.172</td>
<td>1.169</td>
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<td></td>
<td>Standard deviation</td>
<td>1.174</td>
<td>2.230</td>
<td>3.545</td>
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<td></td>
<td>Minimum</td>
<td>0.011</td>
<td>0.336</td>
<td>0.603</td>
<td>0.098</td>
</tr>
<tr>
<td></td>
<td>Pull-off adhesion $f_b$</td>
<td>0.987</td>
<td>0.515</td>
<td>0.497</td>
<td>0.658</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>0.118</td>
<td>0.086</td>
<td>0.137</td>
<td>0.204</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.662</td>
<td>0.306</td>
<td>0.204</td>
<td>0.306</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>1.299</td>
<td>0.688</td>
<td>0.891</td>
<td>1.274</td>
</tr>
</tbody>
</table>
The test results, in the form of dependencies between the values of parameters $N_{av}$, $K_d$ and $M_p/N$ and the value of pull-off adhesion $f_b$, for the four ways of preparing the bonding surface are shown in figs 4-6. For each of the dependencies a regression line equation (derived by the least squares method) and determination coefficient $r^2$ were determined.

Figure 4 shows the dependencies between pull-off adhesion $f_b$ and average mobility $N_{av}$. It appears that regardless of base surface preparation method, the dependencies are similar, i.e. as average mobility $N_{av}$ increases, pull-off adhesion $f_b$ decreases. Determination coefficient $r^2$ assumes values from 0.7115 for surface I to 0.3417 for surface III.
Figure 5 shows the dependencies between pull-off adhesion $f_b$ and stiffness $K_d$. It appears that regardless of base surface preparation method, the dependencies are similar, i.e. as stiffness $K_d$ increases so does pull-off adhesion $f_b$. Determination coefficient $r^2$ assumes values from 0.5600 for surface I to 0.4091 for surface II.
Figure 6 shows the dependencies between pull-off adhesion $f_b$ and mobility slope $M_p/N$. It appears that regardless of base surface preparation method the dependencies are similar, i.e. as stiffness $K_d$ increases, mobility slope $M_p/N$ decreases. Determination coefficient $r^2$ assumes values from 0.6957 for surface I to 0.3719 for surface II.

7. Conclusions
The interlayer pull-off adhesion in two concrete floor models was determined by respectively the nondestructive acoustic impulse response method and the seminondestructive pull-off method. The aim of the tests was to find out if reliable dependencies between the particular parameters registered using the impulse response method and the pull-off adhesion determined by the pull-off method could be established.

The results of the tests show that regardless of the way of preparing the surface of the base the dependencies between pull-off adhesion $f_b$ determined by the seminondestructive pull-off method and the particular acoustic parameters determined by the nondestructive impulse response method are similar and can be described by rectilinear mathematical functions.

However, the values of determination coefficient $r^2$, calculated for the determined dependencies are not too high and depend on the base surface preparation method. For example, the highest value (0.7115) of this coefficient was obtained for a ground surface covered with a bonding layer and parameter $N_{av}$ and the lowest value (0.3417) was obtained for the raw post-concreting surface and parameter $N_{av}$.
Considering that the values of determination coefficient $r^2$ yielded by the impulse response tests are not too high, it seems that several parameters, including the ones describing the topography of the base surface, should be taken into account simultaneously in order to increase the reliability of the nondestructive evaluation of the interlayer pull-off adhesion in concrete floors. The parameters can be nondestructively determined before the topping is laid. Research towards this aim is underway and artificial neural networks are to be used in order to interrelate a larger number of parameters.

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References