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IN-SITU EVALUATION OF CONCRETE INTERLAYER ADHESION BY VIBRATION IN GARAJE FLOORS

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ABSTRACT

A new practice in the construction of garage floors of residential and office buildings in Spain, is to build the concrete slab in two steps: one thick layer at the beginning of the work (≈ 12-35 cm) and a second thin layer (≈ 8 cm) at the end of it. This procedure creates a cold joint between the two layers that may eventually get loose or even split and produce noise when driving over it.
We have designed a nondestructive test to perform in situ measurements to determine the level of fixation of two layers of any concrete slab that causes noise emission problems.
The test is independent of the characteristics of the slab thanks to statistical tools applied to the data.
Vibration induced by a source, the passage of a car, was measured at several locations, with loose and well-fixed layers. The vibration was recorded with a vibrometer. The test can be applied, and the results are compatible with the known state of the slab: we obtain 77.0% sensitivity and 54.5% specificity, while there are only 1.0% false positives and no false negatives. The only drawback of the test is its high number of undecidable cases, which amounts to 24.1%.

Keywords: *Concrete layers bond, Non-destructive test, Accelerometer, In-situ test.*

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1. INTRODUCTION

Traditionally, basement floors were constructed as a single layer concrete slab, which was then polished. However, the work done on this slab often ruined the final construction treatment, which had to be repaired at the end. As a time-saving alternative, the basement floors are constructed in two layers. A first thick layer is made at the beginning, which is the support for all the works during the construction. A second thin layer is applied a few days before the inauguration of the building in order to finish the garage floor without deterioration.
However, this solution has a disadvantage in the form of a cold joint between the concrete layers. Because they are applied at different times and work has been done on top of the first layer, dirt or other debris can accumulate on top of it and weaken the joint with the second layer.
Numerous studies have been conducted about pavement health and vibration [1-6]; however, these studies do not align with the particular problem described above.
We evaluate this problem by performing a non-destructive test on the slab using vibration data.

2. METHODOLOGY

Two experimental procedures were carried out in the study, each designed for a specific purpose in relation to the evaluation of adhesion between concrete layers through vibration measurement:

2.1 Laboratory Measurements:

This first procedure is focused on evaluating the ability of vibration measurements to discern the bond state between two layers of material (concrete and MDF).

In a controlled laboratory environment, based on the facilities described in Annex A of ISO 16251-1 [7], an experimental setup was created where a concrete slab was used as the bottom layer and an MDF (medium density fiberboard) as the top layer. The two layers were bonded together with a material that simulates adhesive (gypsum), and different levels of fixation were varied between them. Vibrations were generated using a standard tapping machine and measured with a vibrometer.
This approach provided consistent and repeatable data, demonstrating that it was possible to detect differences in bonding between the layers depending on the percentage of surface area covered by the adhesive.

2.2 In-situ measurements:

The study measures vibrations in a real building's basement floors. The building, located in Madrid, was constructed between 2016 and 2017 and delivered in May 2017. A few months after the building's completion, variable noises were noticed coming from the garage floor when vehicles passed. All procedures were carried out in accordance with ISO 2631 [8].
To ensure reality's representativeness, measurements were obtained as a light vehicle (Land Rover Discovery Model HSE Sd6) traversed the pavement. The 2249-kilogram vehicle was driven at 20 kilometers per hour (the garage's maximum speed) and vibration levels were measured. The driver started moving from a certain distance to ensure the correct speed at the moment of passing in front of the accelerometer. Data acquisition began when the vehicle started moving and ended when it was far enough away for the vibration to stabilize. A time-dependent vibration history between 1 Hz and 80 Hz was obtained for each pass. The measurements were obtained using a triaxial accelerometer attached to the pavement with a wax disc. The accelerometer was positioned to allow the vehicle to pass through the central roadway. The vibrations were measured in three directions: *Z* axis, vertical; *Y* axis, parallel to the line of pillars inside the garage; and *X* axis, perpendicular to the previous one. The accelerometer was positioned 1.5 m from the nearest parking space. The accelerometer was always positioned away from cracks or defects in the pavement.
The following conditions were fulfilled in all cases:

- The standard vehicle moved forward at data acquisition, staying >1.4 m from the accelerometer.
- Vibration measurements were taken at least 60 seconds apart.
- Vehicles must be in motion forward at the time of data acquisition. Maintain 1.4 meters from the accelerometer and ensure parallel alignment with the Y-axis.
- At least 60 seconds separated each measurement to mitigate the impact of prior vibrations.
- If there was a small unevenness in the pavement that would cause the vehicle to ‘‘jump’’ even slightly, the measurement was discarded.
- Measurements were excluded if the pattern vehicle made contact with a manhole or drain.
- At measurement time, the pattern vehicle was the sole vehicle in the garage.

The operator stayed 1.5 meters from the accelerometer. This allowed them to qualitatively classify the vibrations by the sensation under their feet and the noise generated by movement of the vehicle.
The procedure was replicated 108 times at locations across the floors -2 and -1, so that together they represent a complete study of their surface.

3. DATA ANALYSIS AND RESULTS

3.1 Laboratory results

In the laboratory, the acceleration in the X, Y, and Z axes was measured as the response variables.
The acceleration values for a duration of one second are integrated into a single value by means of the r.m.s., resulting in a value for each second.
The vibration magnitude of the tapping machine is approximately 10^{-4} m²/s² when it is deactivated, and it fluctuates between 10^{-2} and 1 m²/s² when it is activated. This indicates that the ambient vibration is negligible in comparison to that induced by the tapping machine.

Since the vibration source is stationary, we can reduce each measurement to a unique value representing an average of the vibration. We have taken the r.m.s. value of each one. In the following we study this single value of each measurement in order to find out the role of the other variables: location of the tapping machine, location of the accelerometer and percentage of fixed surface area (figure 1).

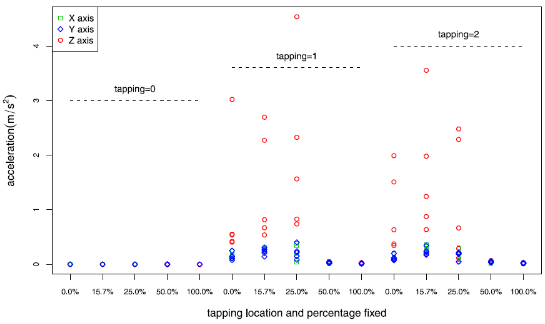

Figure 1. The r.m.s. value of each measurement in the laboratory.

In figure 1, we can see that there is a significant difference in the acceleration values in the Z axis versus those in either X or Y axes, which are significantly lower.
Moving forward, we will exclusively measure acceleration in the Z-axis because it is more sensitive to the effects of the tapping machine.
We can also observe that the percentage of fixed surface area plays an important role when it gets to 50% or higher, in which case the vibration is about 2 orders of magnitude lower than percentages of 25% or below. However, in this figure we do not appreciate differences among 0%, 15.7% or 25% of fixed surface area, nor do we appreciate differences among 50% and 100%.
Given the wide range of acceleration values, it is advisable to use the logarithmic scale for these measurements. To ensure consistency and accuracy in our analysis, it is necessary to establish a reference point for the data. Rather than selecting a single reference value for all data points, we have opted to utilize an average value as a reference point. This approach enables a direct comparison of results from laboratory tests with those obtained from measurements in actual buildings.

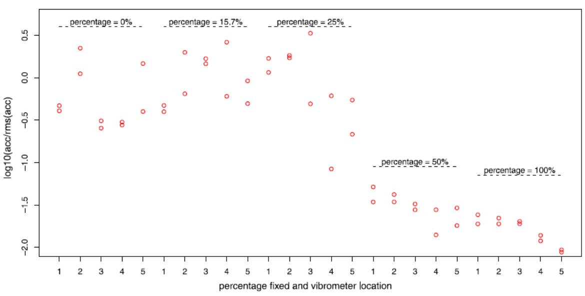

Figure 2. The r.m.s. value of the acceleration in the *Z* direction of measurements in the laboratory.

The results suggest that the recorded acceleration can distinguish between the low percentages (0, 15.7 and 25%) and the high ones (50 and 100%) but not among each of these groups

3.2 Test proposal

We propose a test to classify the degree of fixation between the two layers using vibrational data from an accelerometer. The test will categorize fixation as either low or high. The test will proceed as follows:

- Measure the vertical vibration induced, for instance, by the passage of a car, on the concrete slab. A sample of measurements in different locations is needed, both in locations suspected of abnormal fixation and locations suspected of good fixation between the layers

- Reduce the measurement at each location to a single number, such as the root mean square of the series or the maximum value.

- Compute a suitable average of all the representative values and then compute the decimal logarithm of the representative acceleration in each location relative to the average. The status of the slab layers should be classified using the following criterion:

  Low fixation: locations with a logarithm higher than −0.5.

  Uncertain: locations with a logarithm between −0.5 and −1.0.

  High fixation: locations with a logarithm lower than −1.0.

We use this criterion with data obtained in the garage of an actual building so as to check its validity. In situ results

3.3 In situ results

Figure 3 illustrates four of the 108 recordings obtained in the Madrid building, which exemplify the primary characteristics of all the measurements. Each graph in the figure distinctly captures the passage of the car. Additionally, it is observed that vertical acceleration consistently exceeds the horizontal ones in all cases.

Consequently, from this point on, we will focus exclusively on vertical acceleration.

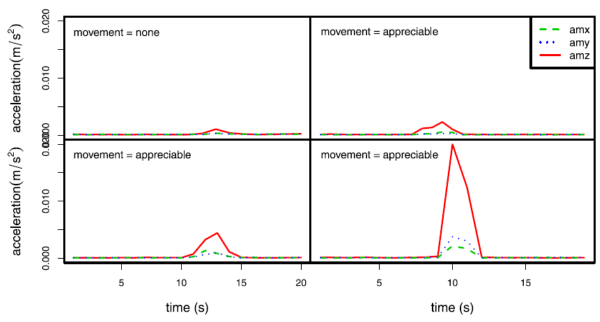

Figure 3. r.m.s. acceleration, with 1 s integration, taken along the passage of the car.

3.4 Test application

Figure 4 illustrates the maximum vertical acceleration of each series, as it relates to the qualitative classification of the movement of the top layer of the pavement. The vertical acceleration is plotted as the logarithm of the value relative to the mean value of all of them.

After applying the criterion defined in Section 3.2 to the data shown in Figure 4, the following results were obtained:

- Seven out of 108 data points, representing 6.5% of the total, have a logarithm lower than −1.0. These data points must be classified as locations where the layers are highly fixed. Only one of these seven locations does not fit into this category.

- 75 of the data, or 69.4%, have a logarithm higher than −0.5, indicating a low fixation of the layers. In this case, all the locations are classified accordingly by the operator, including the 19 locations where a test core was taken, according to EN13863-2 [9], resulting in completely separated layers.

- 26 of the data, 24.1%, cannot be clearly classified by our criterion, as their measurement lies within the uncertain range.

These numbers, though not very impressive, say our criterion may be useful as a first approximation in determining, with a very simple and non-destructive test, the status of the concrete slab in different locations of a garage.

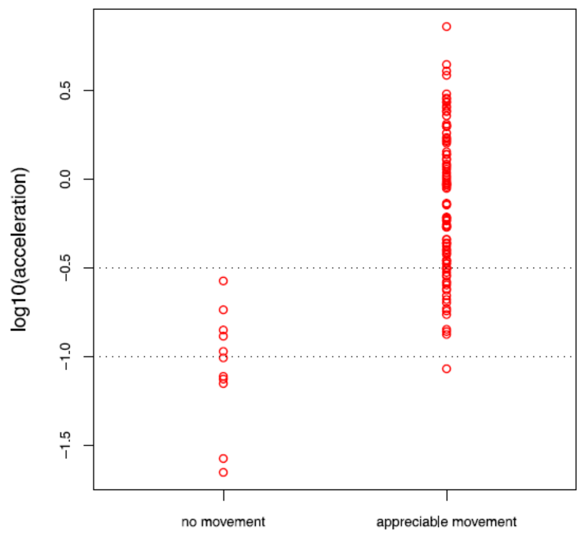

Figure 4. Maximum value of the vertical acceleration in each of the 108 recordings.

4. CONCLUSION

We have proposed a non-destructive test to check the level of fixation of the thin top layer of a concrete slab to the underlying layer using a vibrometer.

We applied our test to data measured in a real building with known fixing problems in the concrete slab of the garage floors.

We measured the vibration past a car in 108 locations within the garage and applied the test previously described.

We found quite a good predictive power of our test, for it classified 82 out of 108 cases, and only one of them was wrongly classified, that is 75.0% where correctly classified.

On the other hand, 26 of the 108 cases were not classified at all, that is a 24.1% of undecidable cases.

As a future work the test should be improved especially by narrowing the interval of undecidable cases.

We are currently extending the study by using the standardized impact machine as an exciter on real building garage floors. We hope to be able to present new results soon.

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