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EXPERIMENTAL STUDY ON CONCRETE PERMEABILITY AFFECTED BY ENVIRONMENTAL VIBRATIO

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This study investigates the effect of environmental vibrations on concrete permeability. Based on published field measurement data and relevant references, two different sinusoidal vibration parameters (5 Hz/4 mm and 20 Hz/2 mm) are selected and applied to a newly constructed concrete by a vertical vibrating table and AC impedance technique. The concrete permeability is examined, and the influence of some factors including different vibration time (before initial curdle, between initial curdle and finial curdle, and after final curdle) and different vibration energy are discussed. From the experimental results, the following conclusions can be drawn. Irrespective of whether or not the concrete is vibrated, the uniformity inside the concrete along the direction of concrete pouring is more discrete in the upper and lower part of the concrete. Furthermore, the permeability at both ends of the concrete is larger than that in the middle portion. The newly constructed concrete's permeability is increased when the vibration energy is lowered, and decreased when the vibration energy is increased, and the new constructed concrete permeability affected by environment vibration obviously before initial curdle time.

Keywords: Newly constructed concrete, AC impedance technique.

1 INTRODUCTION

Concrete related performance without removal form is affected by a certain degree of environmental vibration. In practical engineering applications, there are many factors that can lead to destruction and damage of reinforced concrete structures; however, the durability of such structures is of primary concern. Research on concrete durability affected by vibration has, thus, attracted widespread attention both from academia and industry all over the world, and is found in references such as Kobayashi *et al.* 2016. It is often believed that the durability of concrete is mainly determined by its permeability. Based on our research on concrete permeability using the AC impedance technique, previously used by Wu *et al.* 2016, the impact mechanism of concrete meso-structure affected by environmental vibration is primarily verified, which has considerable usefulness in the actual design and construction of concrete structures.

2 TESTING PROGRAM

Different sinusoidal vibration parameters (5 Hz/4 mm and 20 Hz/2 mm) are selected and applied to a newly constructed concrete, based on field measurements referenced from Ma *et al.* 2015 and combined with other relevant references, such as Zhang *et al.* 2016. Equipment performance is also taken into account while selecting the vibration parameters. The ES-6-230 vertical vibration test system is adopted. The amplitude, frequency and load of the system are seen to satisfy the test requirements. The constructed C40 concrete sample (size: 150 mm × 150 mm × 150 mm and slump is 150 mm) is vibrated at different stages (before initial curdle, between initial curdle and finial curdle, after final curdle) using a vertical vibrating table (Figure 1).

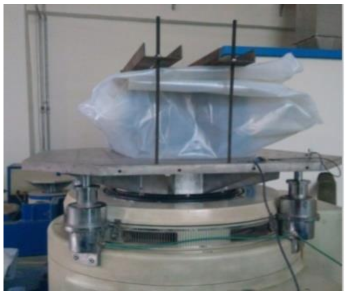


Figure 1. Vibration test.

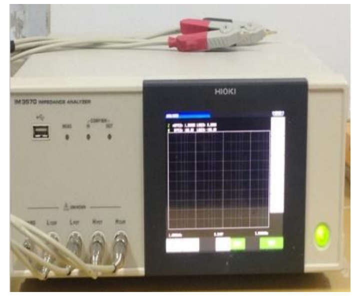


Figure 2. IM3570 impedance analyzer of the concrete specimen in progress.

Table 1. Proportions of the concrete mix.

Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water cement ratio	Sand ratio
472	184	838	956	0.39	0.47

Table 2. Testing plan of the concrete specimen on the vibration table.

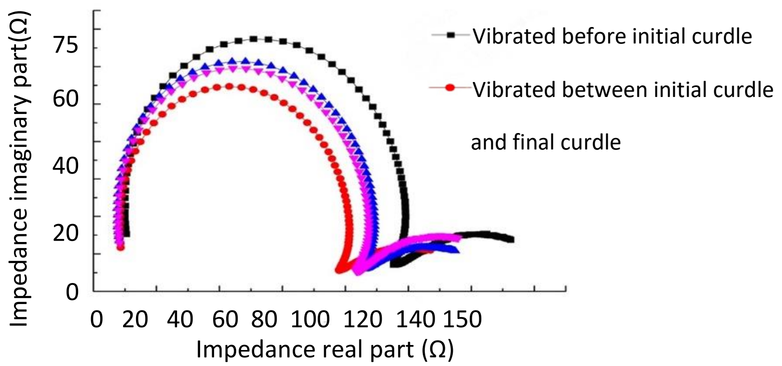
Vibration Parameters	Vibration Form	Vibration Time (in minutes)
1st case 5 Hz/4 mm	Sinusoidal vibration, vibration time = 90 s, pause time = 10 min, in turn, cycle. Simulating the vibration of bridge and roadbed.	Before initial curdle (125-220)
		Between initial curdle and finial curdle (220-315)
		After final curdle (315-410)
2nd case 20 Hz/2 mm	Sinusoidal vibration, vibration time = 4 s, pause time = 2 min, in turn, cycle. Simulating the vibration from explosion and piling.	Before initial curdle (125-220)
		Between initial curdle and final curdle (220-315)
		After finial curdle (315-410)

Note: The vibration time is calculated based on the cement and water contacting in the mixing process.

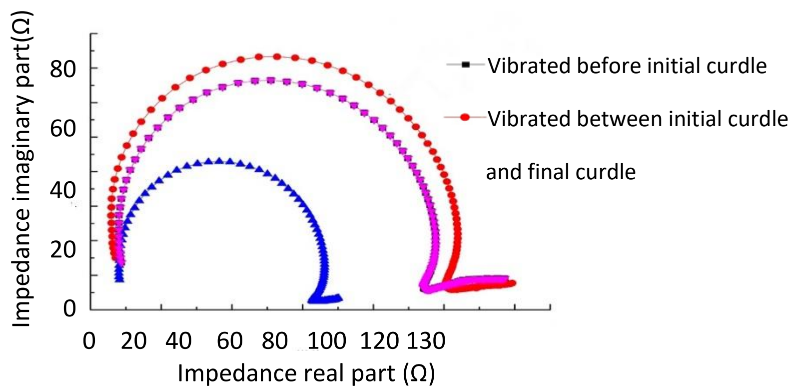
In order to mitigate the adverse effects on specimen shape due to mixing, vibrating, etc, all the cubical concrete samples are processed by removing the uneven layer of five cm thickness on both ends of the sample. The processed samples are cut uniformly into three pieces along the direction perpendicular to the vibration at 7 d. The three pieces of sample are numbered up layer, middle layer and down layer, respectively. After vacuum saturation test finished, the rapid chloride permeability test was performed using IM3570 impedance analyzer (Figure 2) produced by HIOKI company, conducted as per the material testing methods similar to those specified in standard ASTM in America (2012). The proportions of the concrete mix and the vibration table test scheme are shown in Table 1 and Table 2, respectively.

3 EXPERIMENTAL RESULTS AND ANALYSIS

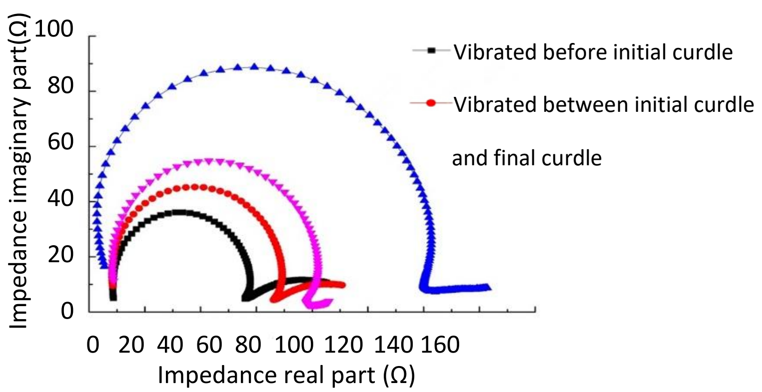
The measured data from the impedance analyzer is analyzed and fitted by using Origin software. The electrochemical impedance spectrums of the concrete in the 1st case are shown in Figure 3.



(a) The upper impedance spectrum.



(b) The middle impedance spectrum.



(c) The lower impedance spectrum.

Figure 3. The concrete electrochemical Nyquist diagram in the 1^{st} vibration case.

And the electrochemical impedance spectrums of the concrete in the 2^{nd} case are very similar with Figure 3.

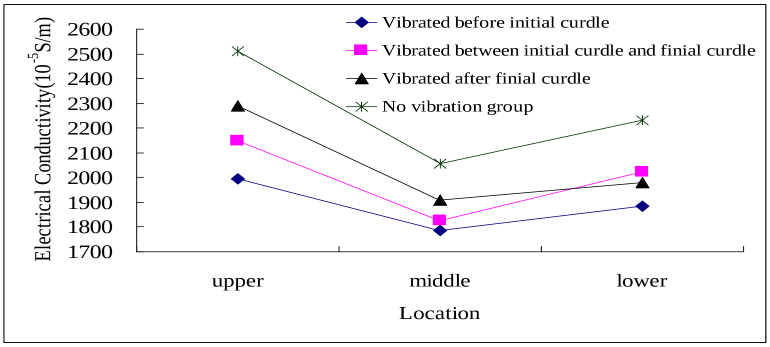
Concrete sclerotic process, the change in the concrete microstructure is investigated by using the impedance technique. The AC impedance is defined as the ratio of input and output signal, and it is also the frequency of complex variable functions, which can be represented by Eq. (1):

$$Z(i\omega) = Z'(\omega) - iZ''(\omega) = |Z| * e^{i\theta} \tag{1}$$

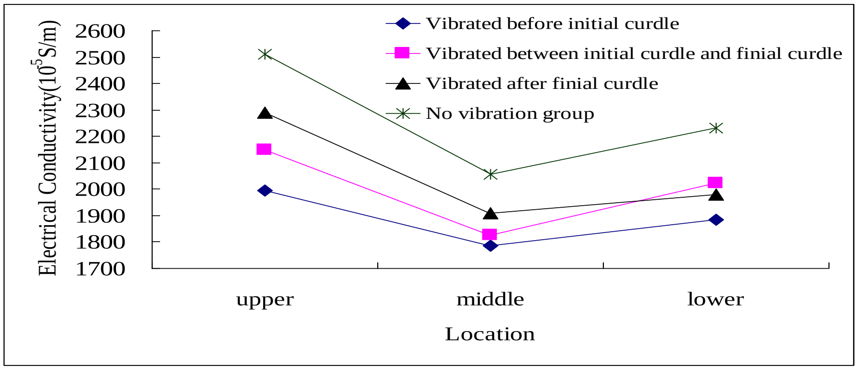
where θ is the phase angle, ω is the circle frequency, and i is an imaginary unit. In Figure 3 and Figure 4, the upper, middle and lower layer is divided from top to down along the direction of concrete pouring. From the fitted Nyquist diagrams, we can see that the impedance curves are roughly semi-circle. The results clearly show the effectiveness of original data and the reliability of fitting are higher, but these preliminary analyses did not find significant regularity, the main reason being the varying thickness of the cut samples. In order to evaluate the concrete permeability more accurately, electrical conductivity is used, which can be obtained from Eq. (2):

$$\sigma = \frac{L}{A} \bullet \frac{1}{R} \tag{2}$$

where σ is the electrical conductivity (S/m), L is the sample thickness (m), A is the cross-section area of the sample (0.0225 m^2), and R is the characteristic maximum of the impedance real part (Ω). The electrical conductivity is calculated for each specimen and the data is plotted in Figure 4.



(a) The electrical conductivity of different concrete layers in the 1st case.



(b) The electrical conductivity of different concrete layers in the 2nd case.

Figure 4. The electrical conductivity of different concrete layers for different vibration cases.

As we can see from Figure 4, overall, irrespective of the stage at which vibration was applied, the electrical conductivity of the upper and lower layer is higher than that of the middle layer.

This illustrates that during the vibration process, coarse particles get deposited at the bottom, excess water gets squeezed up or accumulated below the coarse particles, thus, causing the macro-concrete material to accumulate along the direction of concrete pouring. This drawback is unavoidable during the construction of concrete structures, when the non-uniformity becomes too serious, leading to segregation and bleeding phenomena that are very common in engineering projects. In Figure 4(a), the electrical conductivity of the newly constructed concrete is reduced when the vibration energy is lower, illustrating the reduction in the concrete porosity, and the resultant improvement in the durability of the concrete. In Figure 4(b), the electrical conductivity of the upper and lower layer increases when the vibration energy is higher, but that of the middle layer decreases, thus, indicating the reduction in concrete porosity and subsequent decrease in the durability of the concrete.

It is found that the porosity and strength of concrete are closely related, and permeability is the most important factor in determining concrete durability. In order to properly evaluate the homogeneity of concrete, the electrical conductivity data of each specimen is examined by analysis of variance. These results are shown in Table 3.

Table 3. The AVOVA electrical conductivity results of different concrete layers.

Vibration parameters	Before initial curdle	Between initial curdle and final curdle	After final curdle	No vibration
1st case	85.6	133.2	165.1	187.5
2nd case	380.5	335.2	311.9	101.4

It can be seen from Table 3 that the variance of concrete electrical conductivity between the layers is reduced when the vibration energy is lower, which indicates that the data of concrete electrical conductivity is more stable, causing the concrete layers to be relatively more uniform. The variance of concrete electrical conductivity between the layers is increased when the vibration energy is higher, which indicates that the data of concrete electrical conductivity is more volatile, causing the concrete layers to be more discrete.

4 CONCLUSIONS

(i) Irrespective of whether the concrete is vibrated or not, the uniformity inside the concrete along the direction of concrete pouring is shown to be more discrete in the upper and lower part of the concrete. The permeability on both ends of the concrete is larger than the middle part.

(ii) The change in permeability of the concrete from two different kinds of energy vibration is different from each other as well. The newly constructed concrete's permeability is raised when the vibration energy is lower, and reduced when the vibration energy is higher.

(iii) The newly constructed concrete's permeability is affected by environmental vibration before initial curdle, and between initial curdle and final curdle. However, the permeability remains almost relatively unchanged after the concrete is finally set.

Acknowledgements

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