Application of Impulse Excitation Technique to Investigation of Concrete Damping and Its Changes at Early Ages

Ivan Ivanovich POPOV1,2,*, Ta-Peng CHANG1, Yuri Alexeevich ROSSIKHIN2 and Marina Vyacheslavovna SHITIKOVA2

1National Taiwan University of Science and Technology, Taipei 10603, Taiwan, R.O.C
2Research Center on Dynamics of Solids and Structures, Voronezh State University of Architecture and Civil Engineering, Voronezh 394006, Russian Federation
*Corresponding Author

Keywords: Damping, Concrete, Internal friction, Impulse excitation method.

Abstract. This paper considers experimental results of internal friction test of concrete blocks using impulse excitation technique. Three concrete blocks (120X80X40mm) have been tested at the ages of 7, 14, 28, 56 and 91 days with the Resonant Frequency Damping Analyzer (RFDA) Basic. Mix proportions of the material were selected according to the ACI method. The material of specimens is assumed to be isotropic, and it was proved that this assumption could be applied in practice. It was shown that damping of concrete reduces with time. The most significant changes occur at very early ages, before 14 days. After that this process slows down, however, it continues with lower rate.

Introduction

In all classic engineering and scientific works concrete has always been considered as a purely elastic material. However, this assumption at early ages may not always describe the real behavior of the material. In fact, concrete is a viscoelastic material, especially at early ages. Fresh concrete is a viscous mixture of cement, water and aggregates in a basic composition. After setting concrete increases its elastic performance and reduces viscosity. This process continues during all the period of the concrete hardening. Therefore, concrete with aging transforms from a viscoelastic material to an elastic-like material. In order to describe this transformation, internal friction, as a ratio of the imaginary part of the complex Young’s modulus to its real part, could be applied. Since real part of the complex elastic modulus is related to elastic behavior of the material and the imaginary part describes its viscous properties, then internal friction or damping is an important parameter to understand the properties and behavior of the material.

Impulse Excitation Technique

Impulse excitation method is a relatively new technique for identification of the internal friction or damping of the material. It is based on a light impact applied to the specimen which induces vibrations. Signal is recorded by the microphone and is transformed to RFDA software, which calculates resonant frequencies. For each resonant frequency $f_r$, software calculates damping $Q^{-1}=k/(\pi f_r)$, where $k$ is the exponential decay parameter of each vibration component of frequency $f_r$.[1]. Technical details of the apparatus and software algorithms are explained in [1,2].

Experimental Setup

RFDA Basic is a very convenient instrument to measure the internal friction of different materials. Basic specification consists of RFDA software, USB hardware key, Logitech USB microphone, and Universal wire support, which is shown on Figure 1, reference sample and light-weight impactor.
Since dimensions and mass of the concrete block is much more than the reference sample, reference impactor may not be used to create significant vibrations of the sample. For this reason, it was replaced by another steel spherical impactor, 15.88 mm in diameter. Also, in order to deal with relatively big and heavy concrete blocks authors have designed their own steel wire support (see Figure 2).

Steel wire support 500X500 mm in plan (Fig. 2) has four adjustment screws, which allow one to set up the device in a horizontal position and avoid measurements errors. Other four screws adjust steel wires tension. Such a structure is a good support for concrete blocks 120X80X40mm and over 1200g in mass. It was shown experimentally that the new steel wire support does not affect the accuracy of the measurements. From the comparison of Tables 1 and 2 it is obvious that the either dimensions of the impactor or replacement of the wire support do not have any effect on the measurements.

All of the results obtained in Tables 1 and 2 are in a good agreement with reference data provided by the supplier of the RFDA equipment. This is why it is possible to replace not only standard wire support, but also an impactor. Thus, it is possible to investigate damping of relatively big concrete blocks using RFDA Basic.
Table 1. Measurements result when the reference sample impacted by the reference impactor using steel wire support.

| F, Hz     | Loss rate | Damping | Peak value | F, Hz     | Loss rate | Damping | E, GPa | G, GPa | ν   |
|-----------|-----------|---------|------------|-----------|-----------|---------|--------|--------|-----|
| 8168.61   | 31.1      | 0.001211| 168        | 10488.4   | 29.0      | 0.000880| 209.42 | 80.55  | 0.3 |
| 8168.27   | 29.8      | 0.001159| 126        | 10488.5   | 28.0      | 0.000849| 209.40 | 80.55  | 0.3 |
| 8168.91   | 27.2      | 0.001058| 172        | 10487.2   | 29.5      | 0.000895| 209.44 | 80.53  | 0.3 |
| 8168.72   | 25.1      | 0.000977| 222        | 10489.6   | 23.8      | 0.000721| 209.42 | 80.57  | 0.3 |
| 8168.55   | 25.9      | 0.001009| 173        | 10488.5   | 25.9      | 0.000787| 209.41 | 80.55  | 0.3 |
| 8168.79   | 24.9      | 0.000969| 202        | 10488.6   | 24.3      | 0.000736| 209.43 | 80.55  | 0.3 |
| 8168.56   | 23.6      | 0.000919| 154        | 10488.5   | 22.4      | 0.000681| 209.41 | 80.55  | 0.3 |
| 8168.90   | 25.3      | 0.000985| 270        | 10489.2   | 23.8      | 0.000723| 209.43 | 80.56  | 0.3 |
| 8168.37   | 23.9      | 0.000931| 99         | 10488.5   | 29.2      | 0.000886| 209.40 | 80.55  | 0.3 |
| 8168.57   | 24.9      | 0.000969| 144        | 10489.4   | 36.3      | 0.001103| 209.41 | 80.56  | 0.3 |
| 8168.39   | 23.1      | 0.000899| 211        | 10488.7   | 22.3      | 0.000676| 209.40 | 80.55  | 0.3 |

Table 2. Measurements result when the reference sample impacted by the steel spherical impactor (15.88 mm in diameter) using steel wire support.

| Frequency | Loss rate | Damping | Peak value | Frequency | Loss rate | Damping | E, GPa | G, GPa | ν   |
|-----------|-----------|---------|------------|-----------|-----------|---------|--------|--------|-----|
| 8168.4    | 23.6      | 0.000918| 223        | 10489.2   | 24.9      | 0.000757| 209.41 | 80.56  | 0.3 |
| 8168.8    | 21.4      | 0.000832| 219        | 10488.7   | 33.1      | 0.001005| 209.42 | 80.55  | 0.3 |
| 8170      | 27.2      | 0.001061| 215        | 10488.6   | 26.4      | 0.000800| 209.49 | 80.55  | 0.3 |
| 8169.1    | 21.3      | 0.000832| 220        | 10487.7   | 28.9      | 0.000878| 209.44 | 80.54  | 0.3 |
| 8169.5    | 20.6      | 0.000803| 161        | 10487.9   | 22.2      | 0.000674| 209.47 | 80.54  | 0.3 |
| 8169.5    | 22.9      | 0.000893| 196        | 10489.6   | 26.1      | 0.000792| 209.46 | 80.57  | 0.3 |
| 8169.8    | 25.6      | 0.000999| 236        | 10489.4   | 28.6      | 0.000867| 209.48 | 80.56  | 0.3 |
| 8170.4    | 24.3      | 0.000945| 276        | 10491.1   | 24.9      | 0.000755| 209.51 | 80.59  | 0.3 |
| 8170.9    | 22.6      | 0.000881| 225        | 10490.5   | 29.7      | 0.000901| 209.54 | 80.58  | 0.3 |
| 8170.1    | 24.7      | 0.000963| 256        | 10490.7   | 26.6      | 0.000808| 209.50 | 80.58  | 0.3 |

Experiment and Discussion

Three concrete blocks 120X80X40 mm (see Figure 3) have been casted for the experimental purpose. Mix proportions according to the ACI method are presented in Table 3. Fresh concrete has slump of 140 mm. These mix proportions provide very high compressive strength of the material at early ages. As can be observed from Figure 4, compressive strength at the age of 3 days exceeds 30 MPa and reaches almost 50 MPa at the age of 28 days.

Damping test setup is shown on Figure 5. Since a microphone is used to receive experimental signal and external noise can affect measurements, it is important to conduct the test at relatively quiet place.

Table 3. Concrete mix proportions, kg per cubic meter.

| Water | Cement | Fine ag. | Coarse ag. | Superplasticizer |
|-------|--------|----------|------------|-----------------|
| 213.849 | 484.751 | 796.384 | 881.462 | 2.200 |

Internal friction tests have been conducted at the ages of 3, 7, 14, 28, 56 and 91 days. Damping changes vs. time is shown on Fig. 6, from which it is seen that the most significant reduction of material damping occurs at very early ages, before 14 days. After 14 days this process slows down and continues with lower rate. At each age there is a certain deviation between three corresponding values of damping for each sample. However, this deviation is small and can be explained by the assumption of an isotropic material. Therefore, this assumption could be applied for concrete blocks and RFDA Basic can be used for testing damping of concrete.
Figure 3. Concrete blocks 120X80X40 mm for internal friction test.

Figure 4. Compressive strength development of the concrete.

Figure 5. Damping test setup.
Figure 6. Internal friction vs. time.

Conclusions

RFDA Basic apparatus has been used to test damping of concrete. The assumption of isotropic material was made. According to the results, this assumption could really be applied to concrete material. It was found that internal friction of concrete at early ages has the highest values, which decreases with time. The most significant changes occur at very early ages, before 14 days. After 14 days this process slows down and continues with lower rate. This phenomenon could be explained by the material hardening. Fresh concrete shows the viscoelastic behavior. With hardening, it transforms into an elastic-like material with low viscous properties.

Acknowledgement

The research described in this publication has been supported by RFBR Grant #14-08-9208-HHC_a and National Science Council of Taiwan Grant #NSC 103-2923-E-011-002-MY3.

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