DETERMINATION OF DYNAMIC MODULUS OF ELASTICITY OF CONCRETE BY IMPACT HAMMER

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ABSTRACT – *Experimental determination of dynamic modulus of elasticity of fiber-reinforced concrete (FRC) by using impact hammer is based on measuring resonant frequencies of flexural vibrations in prismatic specimens. The natural frequencies are determined as resonant peaks from frequency response function (FRF), which is obtained by measuring the excitation and response function. The determination of the natural frequencies in this way represents an improvement over standardized test methods. The dynamic modulus of elasticity is determined using fundamental resonant frequency according to relations given in standards. The results are compared to the modulus of elasticity obtained by correlation with compression strength.*

Keywords: *dynamic elastic modulus, fiber-reinforced concrete, non-destructive test method, impact hammer*

ODREĐIVANJE DINAMIČKOG MODULA ELASTIČNOSTI BETONA UPOTREBOM IMPULSNOG ČEKIĆA

SAŽETAK – *Eksperimentalno ispitivanje dinamičkog modula elastičnosti mikroarmiranog betona (MAB) je provedeno korištenjem impulsnog čekića na osnovu mjerenja rezonantnih frekvencija savojnih vibracija na prizmatičnim uzorcima. Vlastite frekvencije su određene kao rezonantni vrhovi funkcije frekventnog odgovora dobivene na osnovu mjerenja funkcije pobude i odgovora. Ovaj način određivanja vlastitih frekvencija predstavlja poboljšanje u odnosu na standardizirane načine mjerenja primjenom rezonantne metode. Proračun dinamičkog modula elastičnosti proveden je korištenjem prve vlastite frekvencije prema izrazima danim u standardima. Rezultati su uspoređeni s modulom elastičnosti dobivenim iz korelacije s tlačnom čvrstoćom.*

Ključne riječi: *dinamički modul elastičnosti, mikroarmirani beton, nerazorna metoda ispitivanja, impulsni čekić*

1. INTRODUCTION

Various non-destructive test methods have been used to explore concrete properties [1]. The aim of this work is experimental determination of dynamic modulus of elasticity of fiber-reinforced concrete (FRC) using non-destructive test method. In this work, impact hammer resonance testing is used. This method is based on measuring the fundamental resonant frequency. The main purpose is to estimate the reliability of resonance testing using an impact hammer in determining dynamic elastic modulus of FRC. The main advantage of this method is that is non-destructive, i.e. it allows repetitive measurements on the same specimen. Moreover, it is applicable on the specimens of different dimensions and shapes.

The ASTM C215 [2] and EN 14146 [3] standards describe the test methods to determine dynamic modulus of elasticity of concrete. These standard tests are based on measuring the fundamental flexural, longitudinal and torsional frequencies of cylindrical and prismatic specimens. In this work only flexural frequencies of vibration are measured on prismatic concrete specimens.

2. FIBER REINFORCED CONCRETE SPECIMENS

Fiber-reinforce concrete (FRC) is composite material consisting from concrete matrix and fibers made from different materials (e.g. steel fibers, glass fibers, synthetic fibers and natural fibers) in various shapes and sizes. The influence of fibers in the matrix of concrete is to improve properties of concrete, especially structural strength and ductility [4]. Compared to normal concrete, FRC have many advantages such as improved durability, toughness, impact resistance and abrasion resistance. On the other hand, inclusion of fibers can cause workability problem of concrete, e.g. formation of fiber balls in the concrete mixture [4]. For most structural and nonstructural purposes steel fibers are the most commonly used. Hence, steel fibers are used in the present concrete mixture.

2.1. Casting and curing of concrete

Specimens used in this experiment are made according to mixture presented in ***Table 1.*** The Portland cement CEM I 52,5 R is used for preparation of the concrete mixture. Further, short steel fibers are used with aspect ratio 65, i.e. fiber length equals 13 mm and diameter 0,2 mm. Volume of steel fibers in concrete mixture is approximately 2%. For more details see [5].

Concrete specimens are kept at 20°C and relative humidity of 100% during the first 28 days after casting, following the procedures recommended by HRN EN 12390-2.

Table 1 *Concrete mixture for FRC*

Material	*Content [kg/ m³]*
Cement	*435,2*
Silica fume	*108,8*
Water	*272,00*
Steel fibers	*200,00*
Quartz sand	*1312,00*
Superplasticizer	*48,00*

2.2. Specimen geometry

For the experimental research cube specimens with dimensions of 150 mm and prismatic concrete specimens of dimensions 100 × 100 × 400 mm are casted. The actual dimension and weight of each prismatic specimen is measured and given in ***Table 2.***

Table 2 *Specimen dimensions*

Specimen	*Widith [mm]*	*Hight [mm]*	*Length [mm]*	*Mass [kg]*	*Density [kg/m³]*
3A	100,76	101,30	399,50	8,890	2180,16
3B	100,54	100,18	400,00	8,675	2153,23
3C	99,50	100,21	400,00	8,650	2168,81

2.3. Compressive strength test

After 28 days of curing the cubes with dimensions of 150 mm are removed from the curing tank, weighted and tested for compressive strength according to HRN-EN-12390-3. The ultimate testing machine with 3000 KN capacity is used. The compressive strength test results are summarized in ***Table 3.***

Table 3 *Compressive strength*

Specimen	*Mass [kg]*	*Density [kg/m³]*	*Compressive strength [MPa]*	*Modul of elasticity, Ecm [GPa]*	*Average value of Ecm [GPa]*
Cube 1	7,395	2194,3	43,54	35,35	35,38
Cube 2	7,340	2204,8	44,37	35,54	
Cube 3	7,320	2172,2	43,05	35,24	

Results obtained during compressive strength test are used to calculate static Young modulus of elasticity according to (1):

$$E_{cm} = 9500 \cdot \sqrt[3]{f_{ck} + 8} \qquad (1)$$

where

E_{cm} is secant modulus of elasticity, and f_{ck} characteristic compressive strength.

Additionally, average Young modulus of elasticity is reported as the mean value of the 3 tested cubes (see ***Table 3***).

3. DETERMINATION OF DYNAMIC MODULUS OF ELASTICITY

3.1. Instrumentation and measuring equipment

To perform the experiment following instrumentation, as shown in ***Figure 1***, is used:

- impact hammer, model 086C03 produced by PCB Piezotronics,
- piezoelectric accelerometer, model 352C33 produced by PCB Piezotronics, with 100 mV/g sensitivity,
- connecting cables for impact hammer and accelerometer,
- data acquisition system Sound and Vibration Data Acquisition model NI USB-4431, to receive and analyze signals received from the impact hammer and accelerometer
- PC

Figure 1 *Instrumentation and measuring equipmen*

-The Sound and Vibration Analysis Software provided by National Instruments to post process results (e.g. finding FRF).

3.2. Test procedure

The striking end of the hammer can be supplied with different impact tips (steel, aluminum, rubber, plastic) to create different frequency response. Therefore, effect of different impact tips is investigated first. Plastic impact tip is found to be the most appropriate for present test specimens, i.e. it produces impulse with the acceptable frequency range.

The experimental test set-up is composed of impact hammer and accelerometer, as shown in Figure 2. The specimen was positioned on the soft foam of density 39,64 kg/m^3 with dimensions 370 × 300 × 65 mm in such way to permit free vibration (see ***Figure 2***).

The test consists of impacting the concrete surface with hammer giving impulse (force) to the specimen. The head of impact hammer is equipped with a force sensor. In order to measure the output response induced by hammer impact, the accelerometer is attached to the top of the specimen in one fixed point, marked as node 6 (see ***Figure 2*** and ***Figure 3***), positioned 50 mm from the edge. Impacts by the hammer are given at exactly determined points, as shown in ***Figure 3***. For every point impacts are repeated 3 times. Signals from the impact hammer (input signal) and accelerometer (response signal) are received by data acquisition system. Ratio of signals received from the accelerometer and signals received from the force sensor of impact hammer in frequency spectral domain is called Frequency Response Function (FRF). The transformation of the recorded time domain

Figure 2 *Tested concrete specimen, accelerometer and impact hammer*

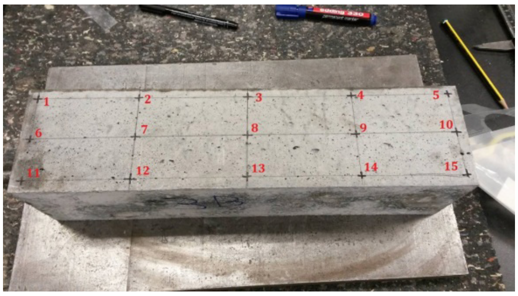

Figure 3 *Points being hit by impact hammer*

data into the frequency spectrum domain is based on fast Furrier transformation. Corresponding FRFs curves are generated using Sound and Vibration Analysis Software.

4. RESULTS AND DISCUSSION

Frequency Response Function (FRF) (see ***Figure 4***) is evaluated in totally 15 points for each specimen. FRF for each point is the average of 3 frequencies obtained from 3 impact point measures to ensure the repeatability of the results. Further, the natural frequencies of specimen in flexure are determined as peaks of FRF and shown in ***Table 4.***

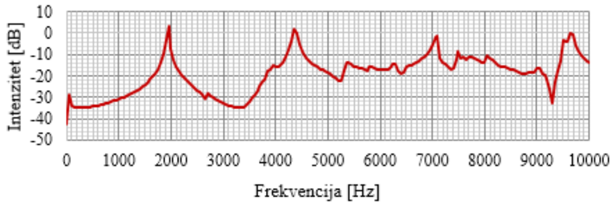

Figure 4 *The frequency response function (FRF) obtained for specimen 3A, point 10*

Table 4 *Natural frequencies for flexure vibration of tested specimens*

Specimen	Natural frequency, f_n [Hz]		
	f_1	f_2	f_3
3A	1950,00	4335,71	7100,00
3B	1900,00	4300,00	7050,00
3C	1950,00	4392,86	7150,00

Once the fundamental resonant frequency is determined (***Table 4***) and knowing specimen dimensions and density (***Table 3***), dynamic modulus of elasticity can be easily calculated by using the equations prescribed in standards [2] and [3].

Dynamic modulus of elasticity according standard ASTM C215 is given by following expression [2]:

$$E_d = C \times M \times n^2 \tag{2}$$

where

E_d – dynamic modulus of elasticity [Pa],

C = 0,9464 (L^3T/bt^3) [$N{\cdot}s^2(kg{\cdot}m^2)$] for the prismatic specimen,

M – mass of the specimen [kg],

n – fundamental resonant frequency of the specimen in flexure [Hz] and

T – correction factor, for tested specimens = 1,39 [2].

The expression of the dynamic modulus of elasticity according to standard EN 14146 (assumption for Poisson coefficient 0,3) is equal to [3]:

$$E_d = 15{,}136 \times 10^{-6} \times l^2 \times F_F^2 \times \rho \times C \tag{3}$$

where

Ed – dynamic modulus of elasticity [MPa],

l – length of specimen [m],

FF – flexure fundamental resonant frequency [Hz],

ρ – density of the specimen [kg/m3] and

C - correction factor, for tested specimens = 1,45 [3].

Finally, the results of the dynamic modulus of elasticity calculated following equations (2) and (3) are summarized in Table 5.

Table 5 *Dynamic modulus of elasticity of FRC*

Specimen	ASTM C215		EN 14146	
	Dynamic modulus, E_d [GPa]	Average value of E_d [GPa]	Dynamic modulus, E_d [GPa]	Average value of E_d [GPa]
3 A	27,07	26,94	29,04	28,34
3 B	26,08		27,30	
3 C	27,66		28,96	

5. CONCLUSIONS

This paper describes the determination of dynamic modulus of elasticity of concrete from flexure fundamental resonant frequency. Based on the results obtained in this study it is found that dynamic modulus of elasticity is slightly lower than the static modulus. However, further investigation is required to have higher accuracy of the results obtained for dynamic modulus of elasticity. With regard to this, parameters such as distribution of fibers in matrix and specimen shape and dimensions need to be analyzed in more detail. Finally, it should be stressed that applied method is simple to use, fast and accurate.

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