Composite Structures 143 (2016) 347–351

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Dependence of polymer concrete vibration characteristics on internal pipe and damper embedment

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ARTICLE INFO

Article history:
Available online 20 February 2016

Keywords:
Dynamic property
Polymer concrete
Pipe embedment
Impact damper
Damping ratio

ABSTRACT

A method to improve the damping characteristics of polymer concretes was investigated. A pipe structure was embedded in polymer concrete specimens. The frequency-dependent variations of the dynamic stiffness and the loss factors of the specimens were measured by the vibration test method to identify the damping enhancement from the embedded structure. The weight reduction effect of epoxy resin usage was compared after the pipe embedment. Impact dampers were applied to the pipe-embedded polymer concretes to improve their vibrational energy dissipation. The impact dampers were fabricated through the insertion of impact balls into the pipe structures. The dynamic properties of the impact-damper-embedded polymer concretes were obtained by vibration tests. The damping performance was investigated according to the gap size between the impact ball and the pipe. An analytic model was used to predict the vibrational behavior of the polymer concrete when the impact dampers were applied. Consequently, the effect on vibration damping was identified for different mass ratios and gaps to find optimal construction.

1. Introduction

Recently, polymer concrete (PC) has become popular as structural materials due to their outstanding strengths and damping performances relative to cement concretes. PC is a composite material mixed with a resin binder and aggregates. PC has high vibration damping characteristics as a result of the interaction between the resin binder and the aggregates [1–3]. To further extend the application fields of PC, various methods of improving the damping capability and strength have been proposed. To increase the strength of PC, fiber-type supplements have been studied. The use of glass and carbon fibers increases the flexural strength of PC. Because the fibers are distributed through the mortar and aggregates, concrete made with such fibers can endure high stress without crack-growth [4–7]. The addition of carbon fibers also improves the dynamic stiffness and loss factors of PC compared to cement concrete [8]. Though the embedment of pipe structures in concrete has been researched [9,10], the use of reinforcement to improve the vibrational stability of concrete has not been a research focus. For this reason, the damping improvement effect of embedding pipe structures in PC should be investigated.

Impact dampers are mass particles placed in a cavity of a structure. One mass particle or a number of light particles like sand are employed in the impact dampers. The cavity surrounding the particles is attached to the surface of the structure or placed inside the structure. The use of impact dampers to reduce the vibration of engineering structures has been investigated [11–14]. The advantages of using impact dampers (as opposed to traditional viscoelastic dampers) are that they are inexpensive, easy to mount to vibration systems, simple to design, and effective on reducing random vibration in wide frequency ranges [15].

In this paper, poly methyl methacrylate pipes (PMMA pipes) were chosen to improve the vibration damping of concretes and reduce epoxy usage during construction. After the PMMA pipes were embedded in the PC, the frequency-dependent variation of the dynamic stiffness and the loss factor were measured with the vibration test method. The measured dynamic properties of PC with embedded PMMA pipes were compared with those of plain PC. The weight reduction ratio caused by the pipe embedment was calculated. To improve the damping characteristics, impact dampers (impact balls inserted in the PMMA pipe) were applied

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http://dx.doi.org/10.1016/j.compstruct.2016.02.031
0263-8223/

to PC specimens. The dynamic properties of the PC after the insertion of the impact dampers with different sizes of pipes and impact balls were investigated. The mechanism of damping enhancement was analyzed with an analytical model. The changes in the damping ratio due to the gap and mass ratio were identified.

2. Experimental study and vibration analysis of pipe-embedded concrete beams

2.1. Fabrication of concrete specimens

The PC specimens were fabricated through the mixture of an epoxy monomer (ERR200 (RM-2), JUNG DO E&P. LTD, Korea), a hardener (ERH200, JUNG DO E&P. LTD, Korea) and two different sizes of aggregates [8]. The sizes of the coarse and fine aggregates were 0.85–1.2 mm and 0.25–0.6 mm, respectively. The epoxy binder was made by mixing the epoxy monomer and the hardener in a 5:1 weight fraction. The weight fraction between the epoxy binder and the aggregates was 1:4, and the dimensions of the concrete beams were 310 × 25 × 25 mm. PMMA pipes (as shown in Fig. 1) were embedded in the center of the concrete specimens to improve the vibration behavior of PC. The diameters of the PMMA pipes were 10, 12, and 15 mm, and the lengths were 310 mm (same as PC specimens). For each specimen, the thickness of the PMMA pipe was 2 mm. For each diameter, three concrete beams were tested. To compare with the flexural strength of the pipe-embedded PC, the cement concrete specimen was also fabricated (the same dimensions as PC specimens). The weight ratio between the water and the mixture of the cement and aggregates (Hanil Cement, Korea) was 1:8. The cement concrete specimen after 30 days from the fabrication was used to the bending test.

Fig. 1. Polymer concretes embedding PMMA pipes.

2.2. Measurement of flexural strength

After the fabrication of PC, the flexural strengths were compared with respect to the pipe diameters. The flexural strengths of the specimens were measured with a three-point bending test on a Kyungsung testing machine (KSU-5M). The loading speed of the flexural tests was 2.36 mm/min [16], and the span was 188 mm. The measured results were averaged for three specimens for the purpose of statistical analysis.

2.3. Measurements of dynamic characteristics

The vibration test method [17] was used to measure the dynamic properties of pipe-inserted PCs. The impact test was used to obtain the vibration responses of the PC beams. The experimental setup of the impact test is shown in Fig. 2. The free–free boundary condition was applied and the impact force was applied at the right end of each beam by an impact hammer (PCB, Type 086C02). The vibration responses of the concrete specimens were measured by accelerometers (Bruel and Kjaer, Type 4507) at two locations (x_a = 0.24 m, x_b = 0.31 m), as shown in Fig. 2. The equation of motion for the Euler–Bernoulli beam is

$$\hat{D}\frac{\partial^4 w}{\partial x^4} + M_b\frac{\partial^2 w}{\partial t^2} = 0, \tag{1}$$

where w is the transverse displacement, $\hat{D} = \hat{E}I$ is the dynamic stiffness ($\hat{E}$ is the elastic modulus, I is the area moment of inertia), and M_b is the mass per unit length of the concrete beam. The harmonic solution, $w(x,t) = \hat{w}(x)e^{i\omega t}$, was assumed to yield the vibration responses of the Euler–Bernoulli beam as follows:

$$\hat{w}(x) = \hat{A}_1 \sin \hat{k}_b x + \hat{A}_2 \cos \hat{k}_b x + \hat{A}_3 e^{\hat{k}_b(x-L)} + \hat{A}_4 e^{-\hat{k}_b x}, \tag{2}$$

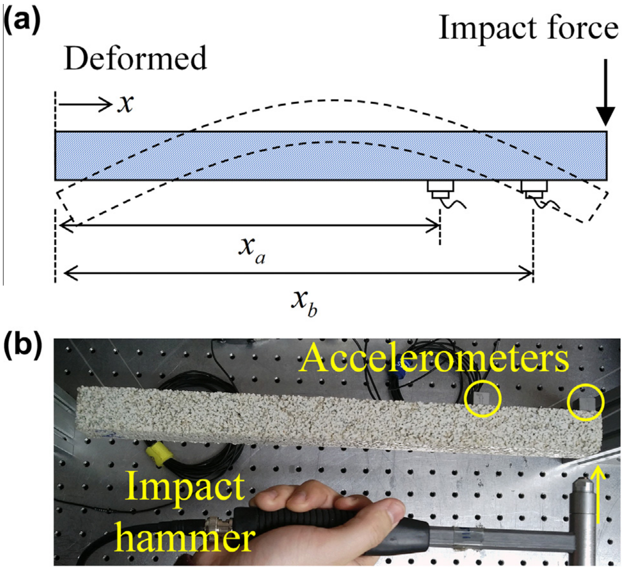

Fig. 2. (a) Geometry of the concrete specimens and (b) experimental setup of the impact tests.

where $\hat{k}_b$ is the wavenumber and A_i $(i = 1,2,3,4)$ are the amplitudes of each propagating wave on the beam and are determined from the boundary conditions. The free–free condition at both ends and the force excitation at right end were expressed as:

$$\frac{\partial^2 \hat{w}(0)}{\partial x^2} = 0, \quad \frac{\partial^3 \hat{w}(0)}{\partial x^3} = 0, \quad \frac{\partial^2 \hat{w}(L)}{\partial x^2} = 0, \quad \hat{D}\frac{\partial^3 \hat{w}(L)}{\partial x^3} = F. \tag{3}$$

After superposing Eq. (3), the predicted transfer function is

$$\Lambda e^{i\phi} = \frac{\hat{w}(x_a)}{\hat{w}(x_b)} = \frac{\hat{A}_1 \sin \hat{k}_b x_a + \hat{A}_2 \cos \hat{k}_b x_a + \hat{A}_3 e^{\hat{k}_b(x_a-L)} + \hat{A}_4 e^{-\hat{k}_b x_a}}{\hat{A}_1 \sin \hat{k}_b x_b + \hat{A}_2 \cos \hat{k}_b x_b + \hat{A}_3 e^{\hat{k}_b(x_b-L)} + \hat{A}_4 e^{-\hat{k}_b x_b}}, \tag{4}$$

where Λ is the amplitude and ϕ is the phase of the transfer function. The predicted transfer functions and measured transfer functions were compared so that the wavenumbers could be