Available online at www.sciencedirect.com
ScienceDirect
Construction and Building Materials 22 (2008) 939–947
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Experimental investigation on dynamic properties of rubberized concrete

L. Zheng [a], X. Sharon Huo [a,*], Y. Yuan [b]

[a] *Department of Civil and Environmental Engineering, 1020 Stadium Drive, Prescott Hall 216, Tennessee Technological University, Cookeville, TN 38505, USA*
[b] *School of Civil Engineering, Tongji University, Shanghai 200092, China*

Received 20 June 2006; received in revised form 28 February 2007; accepted 8 March 2007
Available online 10 May 2007

Abstract

Damping ratio is the main parameter representing the property of materials in vibration reduction. In this study, simply supported beams were tested using a free vibration method to determine the relationships between damping ratio in small deformation and the size as well as amount of rubber particles in rubberized concrete. Elastic wave method and beam element method were used to test the dynamic modulus of rubberized concrete. A comparison between the static modulus and the dynamic modulus was also conducted. It was observed that the damping ratios of rubberized concrete improved considerably compared to those of normal concrete. The dynamic modulus elasticity of rubberized concrete was lower than that of normal concrete. The crushed rubberized concrete had better damping properties but lower dynamic and static modulus of elasticity than ground rubberized concrete. The results of the study provide valuable information for a better understanding of dynamic properties of rubberized concrete.

Keywords: Rubberized concrete; Dynamic modulus of elasticity; Damping ratio; Natural frequency; Elastic wave method; Flexural beam

1. Introduction

Most of barriers, road foundations, dams, and other infrastructural facilities are constructed with concrete materials. Some of these concrete structures are subjected to vibration forces such as impact loading or dynamic shock of moving vehicles. Depending on structural type and dynamic load applied, the induced vibration in a given structure varies in amplitude and in frequencies with excitation source. There is no doubt that dynamic property of concrete material is of significance to these structures, particularly in vibration control and noise mitigation. Furthermore, to avoid resonance of a specific structure at typical modes, whether in material level or member and structural level, damping is helpful in attenuating vibration and reducing resonance.

Cement-based concrete is a kind of brittle material in general and is of high rigidity. However, Topcu [1], Toutanji [2], and Eldin [3] reported that adding rubber to traditional concrete could increase the deformability or ductility of rubberized concrete members. The rubberized concrete could be used in places where desired deformability or toughness is more important than strength, such as road foundations and bridge barriers. Use of scrap tire rubber in concrete (rubber concrete or rubberized concrete) also helped in alleviating disposal waste and protecting environment. Because of the reversible elasticity properties of rubber material, the rubberized concrete could have potential advantages in reducing or minimizing vibration and impact effect. Most of contemporary studies on rubberized concrete focused on the strength or workability of rubberized concrete mixtures [4–10]. Very few dealt with the dynamic characteristics of rubberized concrete material until a recent study by Hernandez-Olivaresa et al. [11]. In Hernandez-Olivaresa's research, the Young

* Corresponding author. Tel.: +1 931 372 3188; fax: +1 931 372 6239.
E-mail address: xhuo@tntech.edu (X. Sharon Huo).

0950-0618/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2007.03.005

dynamic modulus of rubber-filled concrete at low frequencies and the dissipated energy in viscoelastic regime and under compressive dynamic load were studied. A clear dependence on age, frequency, and fiber volumetric fraction was observed. Dissipated energy was larger under higher frequency than under lower frequency. Specimens with higher fiber volumetric fraction (5%) dissipated more energy than lower contents of fiber (3.5%). In all cases, the high percentage of the specific energy dissipated (between 23% and 30%) was observed, which made the material with high contents of recycled tire rubber an optimal candidate for absorbing and dissipating energy under dynamic actions without damage. However, Hernandez-Olivaresa et al. dealt only with the experimental dynamic measurements of specimens with very low rubber volumetric fractions (3.5% and 5%).

The dynamic properties of concrete material system include three primary parameters: dynamic modulus of elasticity, natural frequency, and vibration damping. These three properties interact with each other. Dynamic modulus is a characteristic on the dynamic response of the material; damping is the characteristic of energy dissipation of the material; and natural frequency is a characteristic associated with the material and structure system. Damping of a system can be manifested in the form of the decay of free vibrations. Vibration damping is valuable for structures because it mitigates hazards (whether due to accidental loading, wind, ocean waves, or earthquakes), increases the comfort of people who use the structures, and enhances the reliability.

In this study, rubberized concrete was designed by replacing coarse aggregate in plain concrete with scrap tire rubber in various volume ratios and by using two typical sizes of scrap tire rubber particles. The objectives of the research were to investigate: (1) the difference in the dynamic properties between plain concrete from a control mix and rubberized concrete; (2) the dynamic properties of rubberized concrete including frequencies, dynamic modulus, and damping; (3) the effect of rubber types and rubber content on dynamic properties.

This research focused on the results of the first modal damping that is of primary importance for dynamic calculations undertaken during the design process [12]. Furthermore, first modal bending, as determined from the study, tends to be at the lower end of the range and is therefore conservative [13].

2. Principles of analysis

2.1. Natural frequency

For a simply supported beam subject to a flexural free vibration, natural frequencies may be predicted from the physical properties of the beam using the equation

$$f_n = \frac{n^2\pi}{2}\sqrt{\frac{EI}{ml^4}}, \tag{1}$$

where f_n is the frequency of the nth mode, n is the number of the mode. For natural frequency, $n = 1$. E is the dynamic modulus of elasticity, I is the moment of inertial, l is the length of simply supported beam, and m is the mass of beam member in unit length.

2.2. Dynamic modulus of elasticity

Once frequency was tested on simply supported rubberized concrete beam members, according to Eq. (1), dynamic modulus of elasticity could be determined by Eq. (2). This method is named in this paper as beam element method.

$$E = \frac{4mf^2l^4}{I\pi^2n^4}. \tag{2}$$

The other method used in this paper to determine the dynamic modulus of elasticity is by testing the wave velocity in rubberized concrete specimens. Velocity in rubberized concrete not only has relationships with dynamic modulus E_d, but also with Poisson's ratio v. By measuring V_p the elastic wave velocity of the longitudinal wave (P wave) and V_s elastic wave velocity of the transverse wave (S wave) in rubberized concrete, dynamic modulus of elasticity E_d can be calculated. The relationships between physical properties and wave velocities V_p and V_s [14] are listed in Eqs. (3) and (4):

$$V_p = \sqrt{\frac{E_d}{\rho}\frac{1-v}{(1+v)(1-2v)}}, \tag{3}$$

$$V_s = \sqrt{\frac{E_d}{\rho}\frac{1}{2(1+v)}}, \tag{4}$$

where ρ is the density of the material.

Combine Eqs. (3) and (4), Poisson's ratio v can be obtained:

$$v = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}. \tag{5}$$

Once V_p and V_s are known, E_d can easily be determined by the following equations:

$$E_d = \rho V_p^2 \frac{(1+v)(1-2v)}{(1-v)}, \tag{6}$$

$$E_d = 2\rho V_s^2(1+v). \tag{7}$$

2.3. Damping ratio

For the flexural beam vibration excited by an impact, the damping ratio (ς) was determined based on typical logarithmic decrement tests [15]. The values of acceleration amplitude measured by using an accelerometer could be used to calculate logarithmic decrement by the formula

$$\varsigma = \frac{1}{2n\pi} \times \ln\left(\frac{A_0}{A_n}\right), \tag{8}$$