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Effect of recycled coarse aggregate to damping variation of concrete

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HIGHLIGHTS

- Damping ratio and vibration frequency of RAC are obtained by the suspension test.
- Effect of RCA content on vibration frequency and damping ratio of RAC is studied.
- Damping increase and variation of RAC are caused by complicated old and new ITZs.

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ABSTRACT

Damping properties of recycled aggregate concrete (RAC) at different replacement percentages of recycled coarse aggregates (RCA) were tested by the suspension method. The test results show that the damping ratio of RAC was higher than that of conventional concrete when the compressive strength was similar, while the vibration frequency of RAC was lower than that of conventional concrete. Compared to conventional concrete, the frequency of RAC with 100% RCA reduced by 11% and its damping ratio increased by 17%. The damping variation of RAC is mainly caused by the new ITZ and old ITZ. It can be expressed by the overlay of the damping distributions associated with the two types of ITZs.

1. Introduction

Environmental groups estimated that approximately 136 million tons of waste are generated annually in the United States from construction and demolition of buildings [1]. In the composition of construction and demolition waste, concrete accounts for a large proportion. Recycled aggregate concrete (RAC) is prepared using recycled aggregate from crushed solid waste partly or completely to substitute the natural aggregate. The application of RAC is an effective method to solve the environmental problems caused by construction and demolition waste. A large number of studies in China have shown that the mechanical properties of RAC are not significantly reduced when compared to those of conventional concrete, and can be used to replace conventional concrete in some projects [2,3].

Damping is the ability to convert the vibration energy of a system into other forms of energy, which makes the free vibration amplitude of the system reduce gradually during the vibration process [4]. The damping of a structure includes friction damping inside the material, the medium damping of the air or water, the friction damping among the nodes, the support and the components [5–7]. The damping ratio of a material is an important index to reflect the dynamic property of the material, so it is very important in the dynamic analysis of building structures [8]. However, the recognition accuracy of the damping ratio is much lower than that of the natural frequency and the vibration mode, and often exceeds 30% of the error range [9]. Therefore, it is difficult to establish a practical damping model by means of fine theoretical analysis up to the present. In order to establish a damping model for concrete, it is necessary to find the source of damping in microscopic and mesoscopic and use statistical methods for analysis.

Elmenshawi et al. [10] reported that cumulative damage is more concentrated and harmful in an asymmetric beam, which has smaller damping than a symmetric one. The first load cycle has a significantly higher effect on the equivalent viscous damping ratio than the third cycle at the same displacement ductility. Franchetti et al. [11] proposed a quadratic nonlinear damping factor, which can reflect the actual energy dissipation mechanism in prestressed reinforced concrete members associated with different

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levels of damage. Yan et al. [12,13] used a free-free beam vibration excited by an impact to investigate dynamic properties of fiber reinforced concrete. They found that the damping ratio decreases and the response frequency increases with vibration cycles.

The previous studies have shown that the material composition in concrete, including internal voids and defects, affects the damping property of concrete. However, there are very limited studies on the damping of RAC from the material level. Liang et al. [14] studied the vibration of reinforced RAC and found that the propagation of micro-cracks, the friction within micro-cracks and macro-cracks, the compression and expansion of the air in voids existed in old mortar all contribute to energy dissipation. However, it cannot fully reflect the damping properties of RAC because the rebar has a great impact on the damping property. Therefore, the damping property was studied by using RAC prisms in this paper. It contains more interfacial transition zone (ITZ) in RAC than in conventional concrete and these ITZs may present micro damage or cracks, so the dynamic property of RAC has a distinct difference to that of conventional concrete.

2. Research significance

The damping ratio is a very important parameter in the dynamic analysis of concrete structures. When it contains RCA, the damping mechanism of RAC is more complicated than conventional concrete. At present, the research of damping is mainly focused on the component level, while the research on the mechanism of damping at the material level and the corresponding simplified model of vibration are very limited. The damping mechanism of RAC is mostly based on the speculation and the observation after cracking. In this paper, the damping mechanism of RAC is studied based on the damping ratio distribution of RAC. The main influencing factors of damping are determined from the ITZ, the pores of mortar matrix and the damage of mortar matrix, and then a damping model for the vibration analysis of RAC is obtained. The damping model can be used to estimate the damping property of RAC, and will provide a basic model for the research of RAC components vibration.

3. Experiment procedure

3.1. Specimen design

The cement used in the experiment was grade 42.5 ordinary Portland cement. Natural coarse aggregate (NCA) was limestone gravel, the size of which was in 5–25 mm, the apparent density at natural state was 2620 kg/m^3, the porosity was 44.3% and the crushing index was 7.2%. The fine aggregate was river sand. Water was obtained from the public water supply network. In order to increase the workability of concrete, VIVID-500 polycarboxylate superplasticizer was added. RCA was obtained from concrete waste recycling plant, the size of which was in 5–25 mm. The apparent density of the RCA at natural state was 2536 kg/m^3, the water absorption was 5.8%, and the water content was 3.3%. The gradation of RCA meets the requirements of Chinese codes [15]. In order to analyze the difference between conventional concrete and RAC, a trial experiment of compressive strength and mixing ratio adjustment was done before the damping test. The final mixture proportions of the RAC with different RCA replacement percentages were designed based on equal strength, as shown in Table 1. The shape of RCA is shown in Fig. 1. Using the sample of 150 mm × 150 mm × 150 mm, the cube compressive at 0, 30%, 50% 70% and 100% RCA replacement percentages are 50.1 MPa, 46.8 MPa, 47.8 MPa, 45.7 MPa, 45.4 MPa. According to the Chinese code [16], when the strength grade of concrete is between C25 and C45, the value of σ is 5 MPa, so the concrete under different replacement percentage of RCA can be considered to have a same strength grade.

The size of the specimen used in the damping test is 100 × 100 × 300 mm. The size of the cube specimen is 100 × 100 × 100 mm. Before mixing, the additional water was used to wet RCAs, and then the wetted RCA were mixed with other mixing constituents to produce RAC. Six prism specimens for each RCA replacement percentage were casted for testing damping property. The RAC at different RCA replacement percentages were named with the combination of R and replacement percentage, namely R0, R30, R50, R70 and R100.

3.2. Damping test

The support method of specimen is suspension. Using longer suspension rope, the influence of the sway can be ignored. In the horizontal plane, the test specimen do an unconstrained free vibration. The specimen installation and sensor arrangement are shown in Fig. 2. In the test, two nylon ropes were used to hang the specimen on a steel pipe, and adjusted to ensure the specimen in a horizontal direction. Two piezoelectric acceleration sensors were installed at two sides of the specimen, and an impact hammer was used to tap the specimen. The frequency measurement range of the sensor was 0.5–5000 Hz. A dynamic signal test and analysis system was used for signal acquisition.

Fig. 1. Shape of RCA.

Table 1
Mixture proportions (1 m^3).

Number	Replacement percentage/%	Water/ kg		w/c	Cement/kg	Sand/kg	NCA/kg	RCA/kg	Superplasticizer/kg
		Net	Additional						
R0	0	160	0	0.45	357	683	1080	0	1.78
R30	30	160	3.21	0.44	364	681	749	321	2.18
R50	50	160	5.3	0.43	372	678	530	530	2.45
R70	70	160	7.35	0.42	377	678	315	735	2.72
R100	100	160	10.3	0.41	386	679	0	1030	3.12