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Comparison between dynamic mechanical properties of dam and sieved concrete under biaxial tension-compression

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HIGHLIGHTS

- The dynamic biaxial T-C test data of dam and sieved concrete were obtained and compared.
- Combined effects of stress ratio and strain rate on properties of dam concrete were investigated.
- Dynamic biaxial T-C failure criterion of dam and sieved concrete is established.

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ABSTRACT

A comparative study on the dynamic properties of dam and sieved concrete was conducted based on dynamic biaxial tensile-compressive tests. Specimens were designed to be prismatic shape with a size of 250 × 250 × 400 mm for dam concrete and 150 × 150 × 300 mm for sieved concrete, respectively. Each specimen was biaxially loaded by constant tensile-compressive (T-C) stress ratios (0:−1, 0.05:−1, 0.1:−1, 0.25:−1, 0.5:−1, and ∞) at the strain rate of $10^{-5}\,s^{-1}$, $10^{-4}\,s^{-1}$, $10^{-3}\,s^{-1}$, and $10^{-2}\,s^{-1}$ by a servo-hydraulic multi-axial testing machine. The failure modes of specimens have been compared under various biaxial T-C loading conditions at each strain rate, thus the fracture surface of sieved concrete specimen is smoother than dam concrete. The dynamic strength of dam concrete is lower than sieved concrete under the same loading condition, and the ratio of them is insensitive to strain rate. The growth rates of dynamic strength for dam concrete is consistent with sieved concrete, whereas much larger than ordinary concrete. By regression of the test results, the dynamic T-C failure criterions for dam and sieved concrete were proposed after considering the combined effects of strain rate and stress ratio.

1. Introduction

In order to mitigate the hazard of hydration heat, the component of dam concrete varies greatly from that of ordinary concrete, such as mixing fly ash, increasing the amount of coarse aggregate, and adopting large size aggregates (80–150 mm). Considering the difficulties caused by the large size of specimens, sieved concrete is often used as a substitute for dam concrete when tested, which is made by sieving the aggregate larger than 40 mm from dam concrete [1]. There is a necessity to do special experimental research on the distinctions and relations of mechanical properties between dam and sieved concrete.

The wet sieving effect of dam concrete has been experimentally studied by many scholars [2–5]. Even though the mechanical behaviors of dam and sieved concrete have similarities to an extent, the study indicates that the strength of sieved concrete is significantly greater than that of dam concrete. Previous studies [1,6–7] were limited to static performances, and little attention has been given to the wet sieving effect on dynamic characteristics of dam concrete.

Dam areas are often located in high seismic intensity regions, such as western China. Therefore, nonlinear analysis of seismic response is performed for concrete dam, and effects of loading rate on dam concrete should be taken into account [8–10]. It is widely believed that the strain rate has a large influence on the mechanical properties of concrete, such as strength, modulus of elasticity, critical strain, and poisson ratio [11–15,24]. However, the test results obtained by various researchers differ greatly.

Mass concrete structures, such as arch dams, generally work under a complex state of stress. However, due to the limitation of test equipment, the research on mechanical properties of concrete materials in the past is mostly confined to uniaxial stress

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state. Therefore, the multi-axial stress effect increases the complexity of the experimental research on the dynamic properties of dam concrete [16,25].

Even though some achievements [17–22,27–30] have been obtained in the study on dynamic properties of concrete, it faced with a number of problems, including lack of multi-axial testing data, wide discreteness of data, rarity of comparative analysis between dam and sieved concrete. The objective of this article is to introduce a comparative experimental research on dynamic behavior of dam and sieved concrete under biaxial tensile-compressive loading. The range of loading rate is $10^{-5}\,s^{-1}$ to $10^{-2}\,s^{-1}$, and each stress ratio is kept constant during the loading process. The failure criterion of both considering the combined effects of stress ratio and strain rate was developed.

2. Experimental investigation

2.1. Specimens

Mix proportions for dam and sieved concrete used in this investigation are shown in Table 1. It can be seen that the only difference between the two mixtures is the absence of coarse aggregates greater than 40 mm in the sieved concrete case, leading to a smaller content of coarse aggregates in the latter case. The cementitious material is P.O. 42.5R Portland cement according to a Chinese standard (GB175-1999) produced by Dalian Onoda Cement Plant. Class-I fly ash followed Chinese code GB/T 1596–2005 is used. Fineness modulus of natural river sand is 2.6. The aggregate is crushed limestone with diameter ranging from 5 mm to 80 mm. Water reducer is naphthalene-based superplasticizer of DK-6 type manufactured by Dalian Institute of Architectural Science. Also, several companion cubes were cast for obtaining static cubic compressive strength of dam and sieved concretes ("Guide to Mass Concrete", ACI 207.1R-05). At least 3 samples were tested to ensure that 3 valid data were obtained. The cubic compressive strength of dam and sieved concrete is given in Table 2.

Specimens used for dam concrete and sieved concrete were sized 250 mm × 250 mm × 400 mm and 150 mm × 150 mm × 300 mm, respectively, which are shown in Fig. 1. There are 8 screw bars embedded in both ends to connect the specimen and the tensile loading heads.

The weighed cement, fly ash, sand and aggregate were mixed for about 3 min, then water and water reducer were added and mixed. Vibration of concrete was done with plate-type vibrator associated with insertion-type vibrator. Laminate plywood molds and steel molds were used for dam and sieved concrete, respectively. Before casting concrete, the screw bars were fixed at the both ends of the molds. During the production of specimens, it is reminded to be careful to ensure that the embedded bolts have no vertical deflection. After 24 h, the specimens were removed from the molds, and then placed in the cured room with the temperature of 20 ± 2 °C and the humidity of 95% for 28 days. More details for preparing the specimens can be referred to Ref. [16].

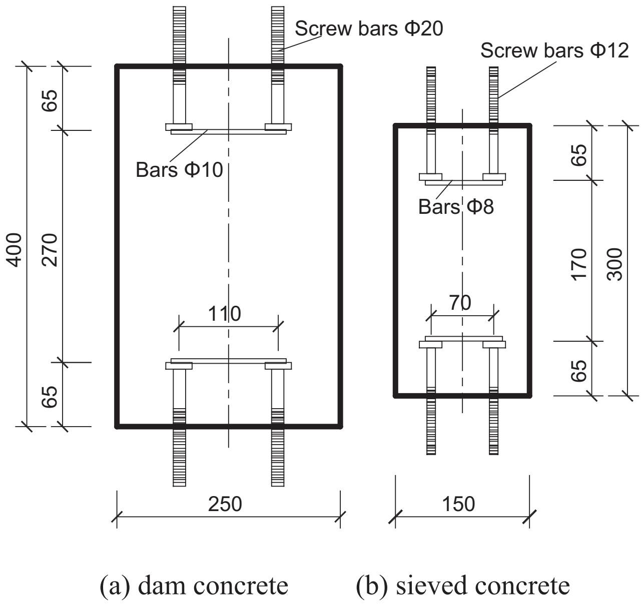

Fig. 1. Specimens size of dam and sieved concrete (unit: mm).

2.2. Testing apparatus

All tests were carried out in the servo-hydraulic multi-axial testing system shown in Fig. 2, which was designed and built at Dalian University of Technology and have made great contributions to the studies of concrete multi-axial constitutive relation and failure criterion [16,17,26]. This testing system has been utilized for dam concrete because of its large size and maximum output of forces, compressive loads of 3000 kN and tensile loads of

Table 1
Mix proportions of dam and sieved concrete (unit: kg/m^3).

	Water	Cement	Fly ash	Sand	Aggregate			Water reducer
					5–20/mm	20–40/mm	40–80/mm	
Dam concrete	120	214	53	549	442.5	442.5	590	214
Sieved concrete	120	214	53	549	442.5	442.5	–	214

Table 2
The cubic compressive strength of dam and sieved concrete.

	Dimension/mm	Age/d	Test data/MPa	Average value/MPa
Dam concrete	250 × 250 × 250	90	17.79 19.13 20.96	19.29
Sieved concrete	150 × 150 × 150	90	25.47 23.41 24.65	24.51