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Dynamic biaxial tensile–compressive strength and failure criterion of plain concrete

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HIGHLIGHTS

- ▶ In the strain rate range 10^{-5}–10^{-2}/s, the dynamic tensile–compressive strength and ultimate compressive strain were obtained.
- ▶ The tensile–compressive failure modes were described.
- ▶ In the strain rate range 10^{-5}–10^{-2}/s, the dynamic tensile–compressive failure criterion was established by fitting the testing data.

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ABSTRACT

Dynamic biaxial tensile–compressive tests have been performed on dog-bone-shaped specimens of plain concrete under different tensile stresses and different strain rates, 100 mm × 100 mm × 100 mm cubic specimens have been adopted in the tests of dynamic uniaxial compression. All tests have been performed by using the large static–dynamic true triaxial test machine. In the compressive direction, the friction-reducing pads have been used, which are made of three layers of plastic membrane with glycerin in-between. In the tensile direction, four bolts have been used to connect the specimen and loading head at the both ends of the specimen. The dynamic tensile–compressive strength, dynamic uniaxial compressive strength and dynamic ultimate compressive strain have been obtained in the paper. The failure modes of specimens have been described. The influences of strain rates and lateral tensile stresses have been discussed. The experimental results have been compared with the results of previous references, in which dynamic splitting tensile tests have been performed under the constant lateral compressive stress. By fitting the experimental data, the dynamic tensile–compressive failure criterion of plain concrete has been established. The dynamic failure criterion can provide the basis for analyzing concrete structural performances under dynamic tensile–compressive load.

1. Introduction

Concrete is one of the most commonly used building materials, it is applied to build house, arch dam, port, bridge, nuclear safety shell, etc. Abrams [1] found that the compressive strength of concrete increases with the increasing of loading rate. There are many research achievements [2–8] about the rate features of concrete. In these investigations, the strength of concrete is increased with the increasing of strain rate, but the increased degrees are different [9]. From Fig. 1, we can see that the relative increase is different at the same strain rate. The difference is caused by several factors, for example, the strength [10], free water [11], initial stress [12,7], W/C [13], size and modulus of aggregate, temperature, etc.

The different loading cases correspond different strain rates, which are respectively creep (10^{-8}–10^{-6}/s), static load (10^{-6}–10^{-5}/s), earthquake (10^{-3}–10^{-2}/s), impact (1–10^{2}/s), blast (10^{2}–10^{3}/s). In this paper, the dynamic performance of normal concrete was studied under seismic load, so the range of strain rates was 10^{-3}–10^{-2}/s. In order to compare with static performances, the range of strain rates was 10^{-5}–10^{-2}/s.

The uniaxial tensile strength of concrete only is one tenth to one eighth of the uniaxial compressive strength [14]. Generally speaking, the tensile strength is used as the indicator of the safety factor calculating the cracking resistance of concrete dam [15]. In applications of concrete, the stress states are complex. There are concrete dynamic characteristics studied under uniaxial compression, uniaxial tension [5,16], biaxial compression-compression [17], and triaxial compression [18]. In buildings and arch dams, the concrete is under the stress state of tension–compression [19]. Under the stress state of compression–tension, the previous static tests show that the tensile component and compressive component of strength are all lower than the uniaxial tensile strength and the uniaxial compressive strength [14,20,21]. So the biaxial tensile–compressive stress state is more dangerous than uniaxial tensile stress state.

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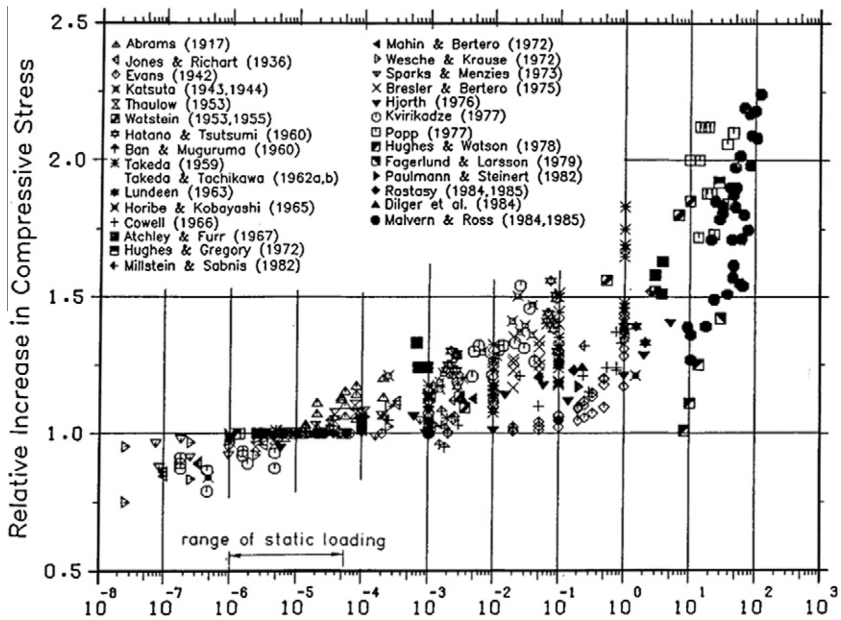

Fig. 1. Strain-rate influence on concrete compressive strength [9].

Under seismic loads and the stress state of tension–compression, the studies of concrete behaviors are very few. In the Ref. [22], the strength of tension–compression is increased with the increasing of strain rate (from 10^{-6}/s to 10^{-3}/s), and the strength is decreased with the increasing of lateral compressive stress.

In this paper, through large numbers of experiments, the strength of plain concrete has been studied in the stress state of tension–compression under different strain rates (10^{-5}–10^{-2}/s). The experimental results have been analyzed. By fitting the experimental data, the dynamic failure criterion has been established in the stress state of tension–compression.

2. Triaxial testing system

Triaxial testing system used in this paper is shown in Fig. 2.

The original triaxial test machine of Dalian University of Technology made great contributions to the studies of concrete multiaxial constitutive and failure criterion [23–26]. In each direction, two actuators were equipped on the new triaxial test system. It can eliminate machinery restraint force of the system, and keeps the force balance in each direction. There are two kinds of controlling modes: load controlling mode and displacement controlling mode. Static test and dynamic test can be carried out by the triaxial test system. The triaxial stress ratio can be adjusted at random.

Fig. 2. Full view of test system.

The maximum output of the testing system: pressure 2500 kN, pull 1000 kN; actuator's stroke is 200 mm; the maximum loading frequency is 12 Hz; the maximum strain rate is 10^{-2}/s. The range of fatigue-type load sensor is 3000 kN, and the accuracy is 0.1%; the accuracy of magnetostrictive displacement sensor's is 0.05%, the accuracy of LVDT's is 0.001 mm.

3. The introduction of experiment

3.1. The concrete mixture ratio

Table 1 shows the mix proportions by weight of the mixture.

The cement was ordinary Portland cement, which was produced by Dalian Onoda Cement Plant. The grade of cement was P.O42.5 (compressive strength is higher than 42.5 MPa at the age of 28 days by the test method of Chinese standard GB/T 17671-1999, which is identical with ISO 679:1989). Natural river medium sand was adopted as fine aggregate, whose fineness modulus was 2.8. Crushed limestone was adopted as coarse aggregate (diameter ranging from 10 mm to 20 mm). Water was tap-water.

3.2. The production of specimens

The concrete specimens were made into dog-bone-shape, which could eliminate stress concentration at both ends of specimen. For insuring accurate dimensions of specimens, steel formworks were made up and used. Before casting concrete, the steel formworks were cleaned, and release agent was brushed on the inside surface of steel formworks. Then the bolts were fixed at both ends of steel formworks.

Crushed stone, sand and cement were respectively weighed and putted into the ordinary forced action mixer by order; then the mixer was turned on, until the materials were mixed homogeneously, the weighed tap-water was slowly poured into the mixer, the mixture were stirred about 3 min.