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Experimental research on the behaviour of high frequency fatigue in concrete

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ABSTRACT

Calculating the fatigue strength of concrete under the cyclic load of vehicles when designing bridges is an issue which is receiving more and more attention from many engineers and researchers. Based on this fact, fatigue tests of plain concrete under constant-amplitude and stepping-amplitude cyclic loads were conducted. The mechanism which damages plain concrete specimens under high frequency fatigue loads was analysed and a non-linear accumulative fatigue formula that causes the damage was proposed. A fatigue equation P–S–N that considers the failure probability p' was given. The results of this research are a good preparation for further studies into high frequency fatigue tests of concrete cylinders reinforced with carbon fibre.

1. Introduction

Bridges over highways and railways suffer cyclic loads from vehicles which cause the structures to fail, but the failure of these structures and their components from fatigue loads are far lower than their original strength. Failure from fatigue is often abrupt and has serious consequences.

Some researchers have already investigated the fatigue performance of concrete. Aas-Jakobsen [1] found there was a good linear relationship between the logarithm of fatigue life and stress ratio f_c^{max}/f_c (f_c^{max} = the maximum value of fatigue compressive stress, f_c = the mean value of fatigue compressive stress), and then obtained the Wohler equation in linear form. Matsushita and Tokumitsu [2] conducted fatigue tests using concrete cylinders. The probability distribution for the fatigue life of concrete was analysed and the S–N (S = stress, N = fatigue life) equation, which includes the lowest fatigue stress level, was put forward. Hsu [3] introduced a loading speed T into the series of f–N–R (f = stress level, N = fatigue life, R = correlation coefficient) equations for fatigue tests on concrete and established the f–N–R–T equation in 3D. He suggested the equations for high frequency fatigue and low frequency fatigue respectively. Mihashi [4] applied the stochastic process theory when estimating to the fatigue life of concrete. Liang and Zhou [5] developed a fracture mechanics based fatigue law for asphalt concrete beams. Based on damage mechanics and tensor theory, Alliche [6] established a three dimensional model for describing the behaviour of concrete fatigue. Sain and Chandra Kishen [7] concluded that for concrete suffering from fatigue, a discrete crack may be modelled as an equivalent damage zone where both correspond to the same loss of energy. Hitherto, many researches have worked on low frequency fatigue in concrete components, whereas research on high frequency fatigue is relatively recent due to limitations in the test conditions.

In this paper, fatigue tests of plain concrete under constant-amplitude and stepping-amplitude cyclic loads were carried out. The mechanism that caused the damage was analysed, a non-linear fatigue accumulative damage model was established

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and a loading frequency correction coefficient that considers how the loading frequency affects the fatigue life was put forward. In addition, probability statistics based on the testing data were analysed and a fatigue equation that considers the probability of failure was proposed.

2. High frequency fatigue tests of plain concrete

The loading frequency for common fatigue tests is usually below 30 Hz, but can reach 100 Hz for high frequency fatigue tests. Under high frequency, the time and cost of reaching the fatigue limit and strength of a material are dramatically reduced. Here, high frequency fatigue tests with constant amplitude and stepping amplitude were conducted.

2.1. High frequency fatigue tests under constant-amplitude and stepping-amplitude cyclic load

2.1.1. Static loading tests

For these tests, 33 cylindrical C30 concrete specimens, 70 mm in diameter by 100 mm high were prefabricated. They were manufactured in plastic moulds and were maintained for 28 days at a temperature of 20 ± 3 °C before being tested.

From the static loading tests it was found that the ultimate loading capacity of the cylindrical specimens was $F_u = 112.11$ kN, so the axial compressive strength is $f_{co} = 29.1$ MPa. The compressive strength of the cubic samples was $f_{cu} = 36.6$ Mpa, and the elastic modulus amounted to $E_c = 4.73 \times 10^4$ MPa.

2.1.2. The introduction of a high frequency fatigue testing machine

High frequency fatigue tests were conducted on ZWICK-100HFP5100 test apparatus, manufactured by the ZWICK/ROELL company, which is shown in Fig. 1. The basic technical parameters of the testing machine include the maximum test load (100 kN), maximum vibration frequency (150 Hz), maximum static loading capacity (100 kN), and maximum dynamic loading capacity (100 kN ± 50 kN).

2.1.3. Test schemes

2.1.3.1. Constant-amplitude cyclic loading tests. The test parameters included the biggest stress σ_{max}, the smallest stress σ_{min}, the mean stress σ_m, and the stress amplitude σ_a. The relationship among the parameters is shown in Fig. 2. Table 1 indicates the loading conditions for the high frequency fatigue tests under constant-amplitude cyclic loads.

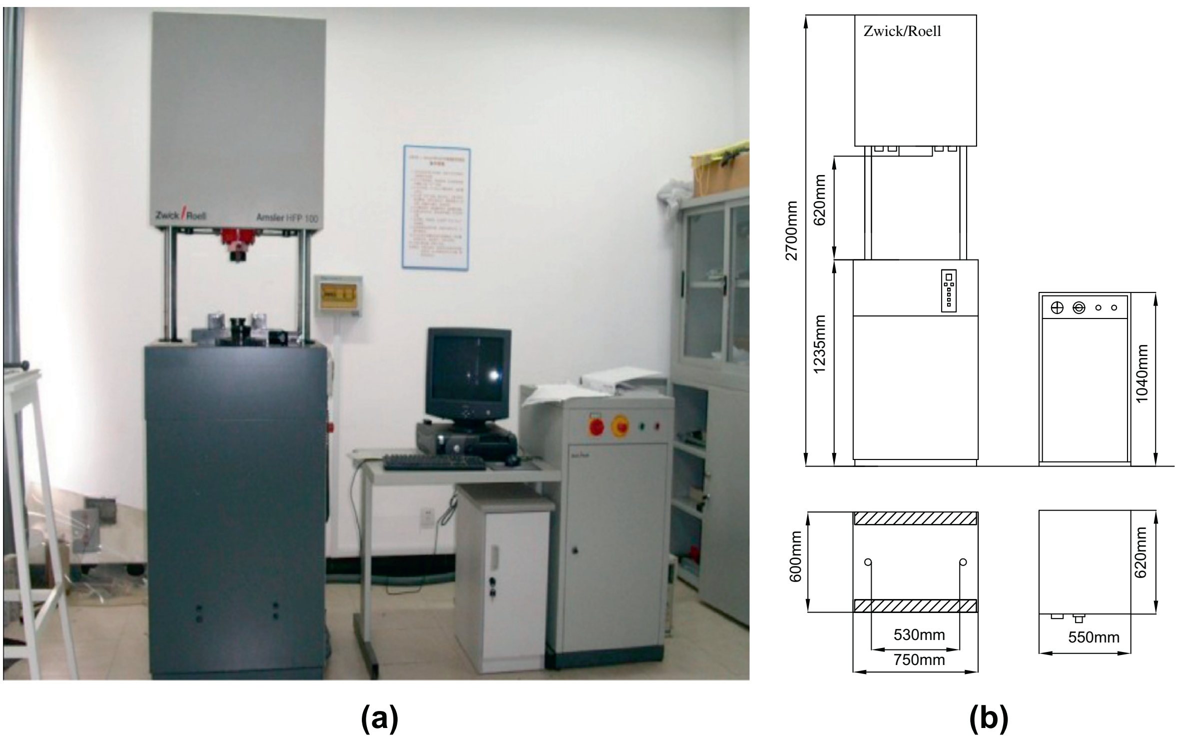

Fig. 1. ZWICK-100HFP5100 test apparatus: (a) ZWICK-100HFP5100; (b) Drawing of ZWICK-100HFP5100 with dimensions.