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A Numerical and Experimental Study of High Strain-rate Compression and Tension Response of Concrete

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ABSTRACT

Unconfined compression and tension tests have been performed on cylindrical samples prepared from a newly developed concrete. A 3-inch Hopkinson bar setup has been employed to experimentally extract the stress-strain relation of the concrete at different strain rates. A novel procedure is introduced to conduct tension tests. Initiation and propagation of cracks in concrete samples are captured by high-speed photography. The experimental data will be used to improve the existing concrete material models.

Extracting stress-strain relations from the Hopkinson-bar experimentally obtained data requires assumptions about the sample size and interface friction between the sample and the bars. The effect of violating these assumptions on the validity of experimentally acquired stress-strain results is explored by performing a full-scale finite element simulation of the entire process. A new method of accounting for the dispersion in the Hokinson cylindrical bars using the finite-element results is introduced and verified by comparing these results with the generally used analytical method. Numerical results reveal that the strain and stress history are not uniform within the sample. The usual method of analyzing the Hopkinson bar experimental results that generally overlook this fact can be corrected by minor calibration on the data.

Keywords: concrete, compression test, tension test, Hopkinson bar, SHPB

EXTENDED ABSTRACT

To characterize the mechanical properties of a newly developed concrete when subjected to dynamic loads, unconfined compression and tension tests have been performed on cylindrical concrete samples. A 3” Split-Hopkinson Pressure Bar (SHPB) has been employed to perform the experiments. SHPB consists of two cylindrical bars, known as incident bar and transmission bar, and a striker, all made from some high-strength material. A relatively thin sample is placed between the bars. A gas gun is employed to accelerate the striker towards the incident bar. The impact between the two generates a pressure pulse inside the incident bar. The shape, amplitude and duration of the pulse can be designed by altering the shape, size and impact velocity of the projectile. When the pulse reaches the sample, some of it is reflected due to impedance mismatch between the bar and sample and some of it is transmitted to the transmission bar. The reflected and transmitted pulses are captured by surface-mounted strain gages on the bars.

Using one-dimensional uniaxial stress wave theory, stress and strain experienced by the sample can be retrieved from the strain gages data (see Nemat-Nasser et al. [1]and Gray [2]) using the following formulas:

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$$\varepsilon_s(t) = -\frac{2C_0}{L_s}\int_0^t \varepsilon_R(t)dt \qquad (1)$$

$$\sigma_s(t) = -E_0\frac{A_0}{A_s}\varepsilon_T(t) \qquad (2)$$

where C_0, A_0 and E_0 are sound speed, cross-sectional area and elastic modulus of the bars, respectively. ε_R and ε_T are the strain histories in incident and transmission bars which can be evaluated from the strain gage data. A few assumptions are made in derivation of these equations. For example, the width of the sample is neglected and the bars have to remain in their elastic region during the experiment. Dispersion of the travelling wave in the bars, which happens because waves with different frequencies travel with different velocities, is also not considered in these formulas. Therefore, generally small samples are used and a dispersion correction routine is used to account for these assumptions. Figure (1) illustrates the schematic view of HSPB for compression tests.

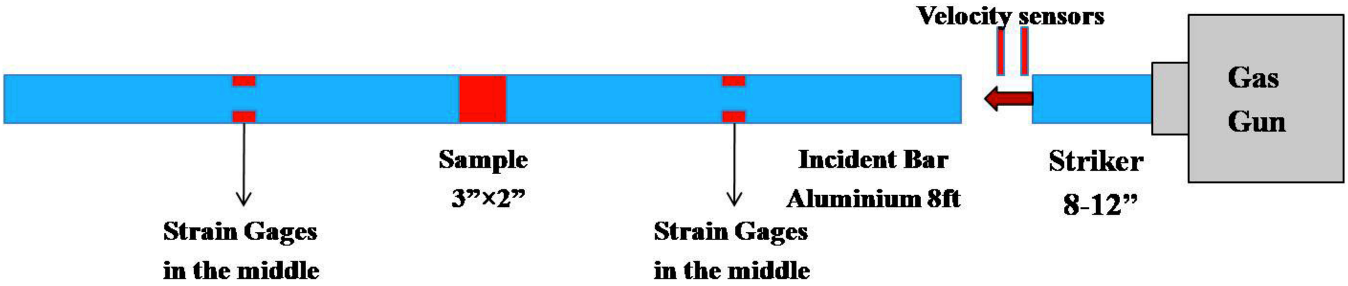

Figure 1. The schematic view of the HSPB for compression tests

Figure (2) shows the compression and tension samples. The average size of the aggregate in the concrete is a defining factor in designing these specimens. The samples are made large enough to ensure that they represent the concrete rather than its components, e.g. aggregate or cement. Therefore 3-inch diameter was chosen for the specimens.

Figure 2. Left: compression sample, Right: tension sample

To generate different strain rates, strikers with different lengths were designed. Figure (3) shows three different input pulses generated for compression tests. A total of 27 tests were carried out and the strain gage data was recorded for each experiment. Using this data, the stress-strain curves at different strain rates were plotted for this concrete.

A finite element model for these experiments was developed to investigate the validity and accuracy of equations (1) and (2) in this case. A well-established concrete material model was used. This model uses the pressure pulse from the experiments (which is captured by strain gages) as an input. Using the simulation results, the stress-strain curve inside the sample is plotted. Also, the time-history of the strain at the location of strain gages in the finite element model is available. Therefore, the stress-strain curve can be plotted using equations (1) and (2). Our simulation results reveal that these two curves are different but close. Therefore, although the specimens are large, using equations (1) and (2) to calculate the stress-strain curve for the concrete is acceptable.

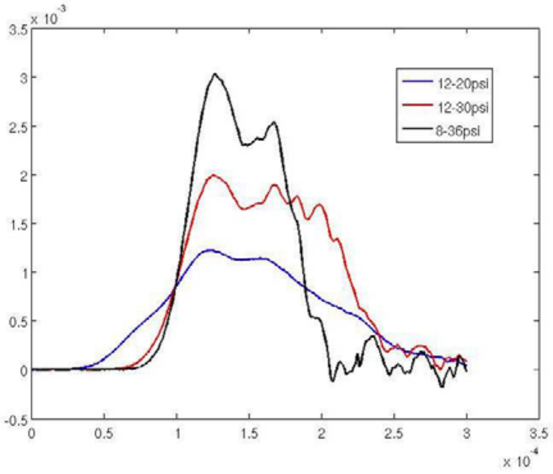

Figure 3. Three different input pulses

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