Determination of Dynamic Tensile Strength of Concrete Using a Split Hopkinson Pressure Bar

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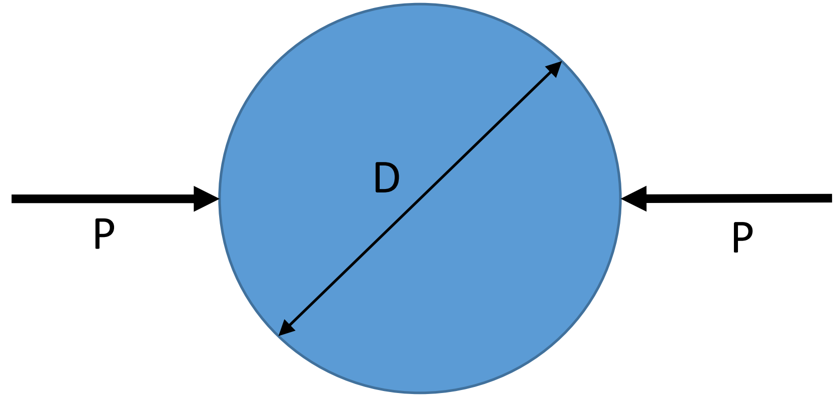
Concrete Failure

- Concrete is a common building material – bridges, buildings, roadways, etc.
- Concrete is strong in compression and weak in tension.
- Failure of concrete structures is often the result of tensile failure.
- Failure of concrete is dependent on the loading rate. [1]
- Design of structure needs to account for loading rate.

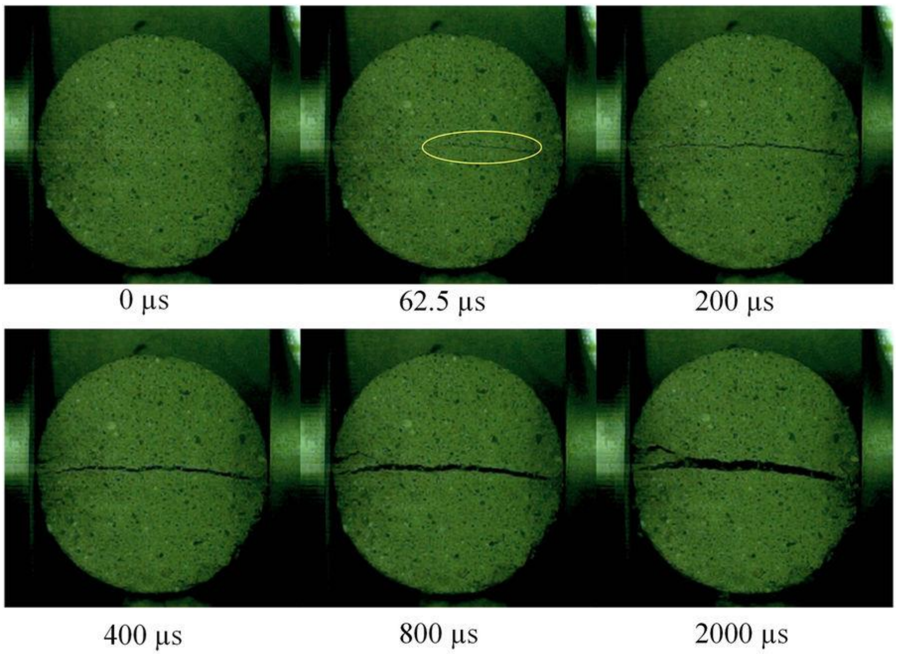
Tensile Testing of Concrete

$$\sigma_t = \frac{2P}{\pi D t}$$

t = thickness of specimen



Brazil Disc Specimen (ASTM D 3967-08):



- Compression creates a tensile failure of the specimen.
- Test can be performed quasi-statically or dynamically at high strain rates.

* High speed imagery of concrete Brazil Disc tes from X. Jin et al [1]

Split Hopkinson Pressure Bar (SHPB)

- In 1914, Hopkinson introduced a technique for measuring dynamic material strength]4]
  - Cylindrical steel bar with pellet lightly attached to end
  - Response of bar determined by measuring momentum of pellet
- In 1948, Davies did a critical review of this experimental technique [5]
  - Microphone and oscillograph used to make photographic record
  - Dispersion correction equations derived
- Kolsky further adapted Davies' method in 1949 by introducing a second bar on the other end of the specimen with a second microphone at the end
  - Record made of both incident and transmitted pulses [2]

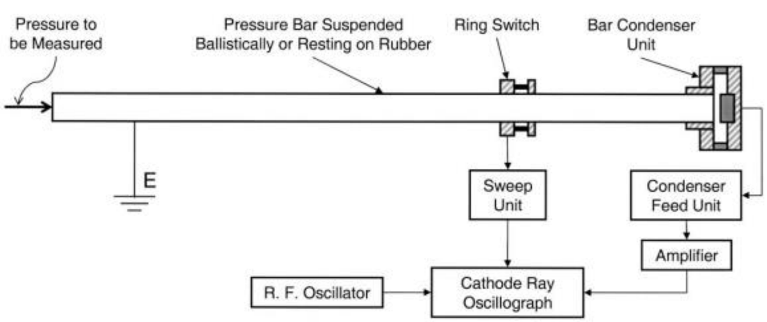


Fig. 2 General arrangement of the apparatus developed by Davies. Reproduced from Fig. 1, Davies [5], p 382. [3]

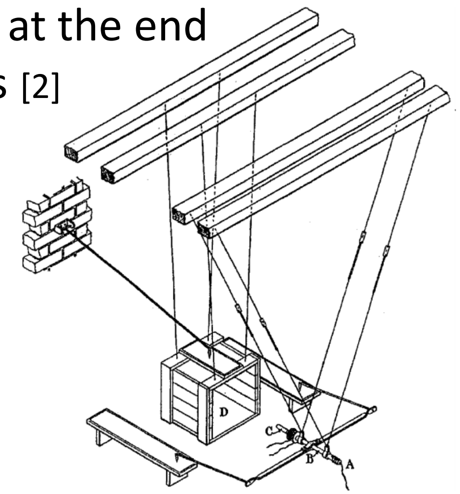
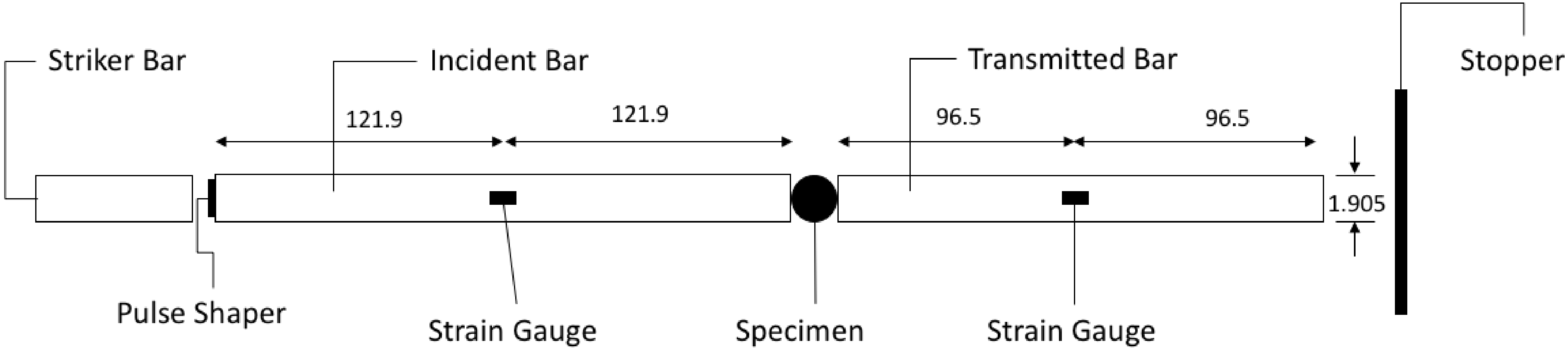


Fig. 1 Apparatus developed by Bertram Hopkinson for the measurement of pressure produced by the detonation of gun cotton. Reproduced from Fig. 12, Hopkinson [4], p 451. [3]

Bar Setup

- Utilizes thin bars to propagate stress wave into sample
  - Thin bars simplify motion into one dimension
  - Bars must be homogenous and have a uniform cross section
  - The impact from the striker bar must not exceed elastic limit of bars
- Strain caused by stress wave is measured at the midpoint of each bar.
  - Full Wheatsone bridge configuration used to isolate axial strain
- Dispersion effects present from finite bars

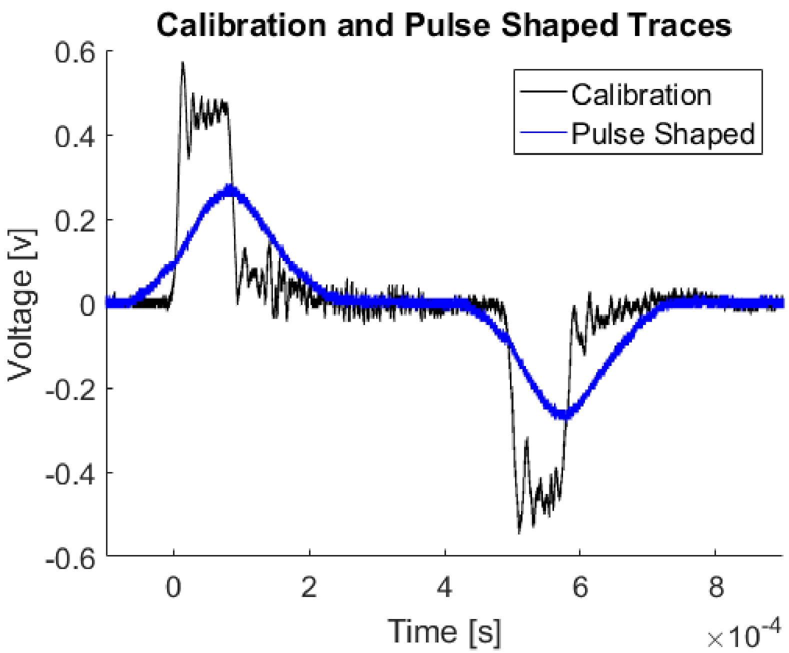


*not to scale

High Frequency Compensation

Pulse Shaping

- Addition of a material between the incident and striker bar – lead, plastic, paper, etc.
- Creates a mechanical filter that reduces frequency content of the impulse wave(s).
- Pulse shaper material depends on SHPB and specimen materials
- Pulse shaped signal should mimic material response of specimen [6]



Dispersion Correction

- Utilize non-linear curve fitting and Fourier series to correct for dispersion [7]

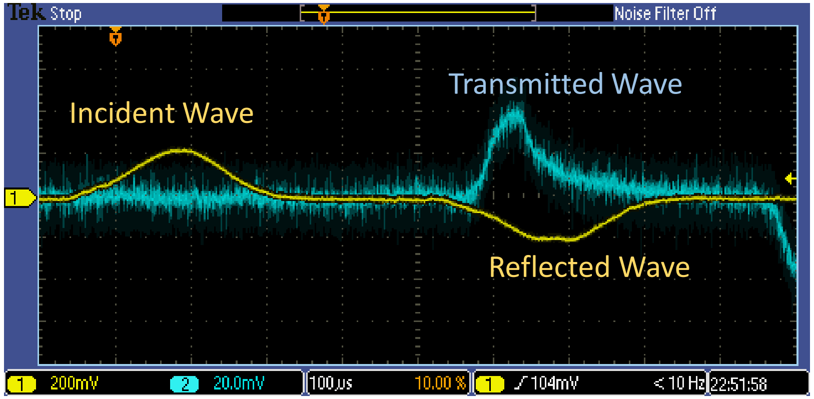
$$F(n\Delta T) = \frac{A_0}{2} + \sum_{k=1,2,\ldots}^{N} \left[A_k cos(k\omega_0 n\Delta T - \phi_{TS}) + B_k sin(k\omega_0 n\Delta T - \phi_{TS})\right]$$ [3]

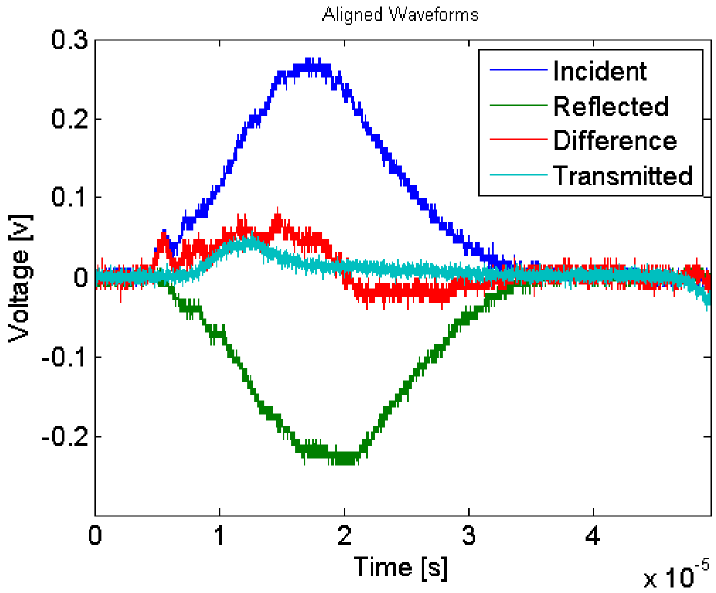
Wave Position Alignment

- Since strain gauges are positioned in the middle of the incident and transmitted bars, waves must be aligned forward/backwards in time.
- Utilizing the bar wave speed and known position of strain gauges – waves are aligned in time.
- Force equilibrium can then be determined by converting voltages to strain.

$$F_1 = A_{Bar}E_{Bar}(\varepsilon_I + \varepsilon_R)$$

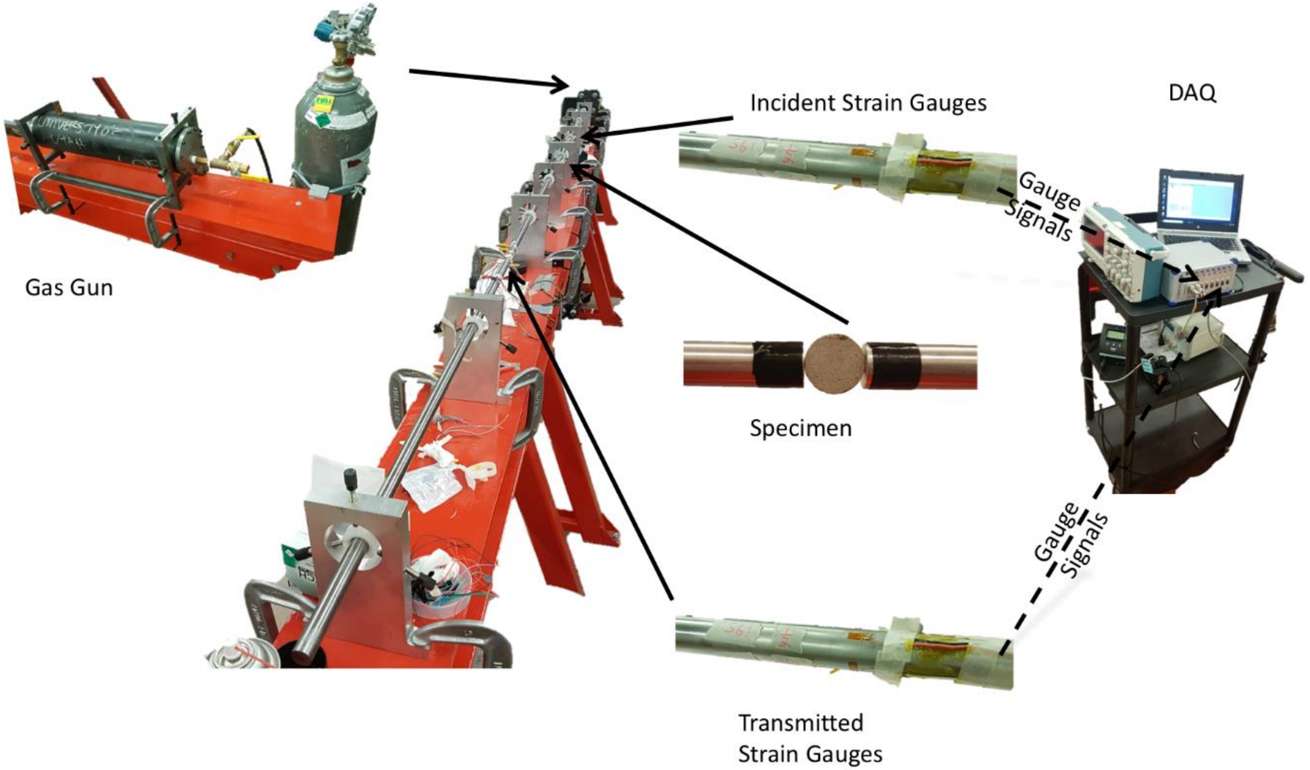
$$F_2 = A_{Bar}E_{Bar}(\varepsilon_T)$$





Test Procedures

- Gas gun was utilized to propel striker bar, pressure was varied from 8 to 12.5 psi.
- Concrete Brazil Disc specimens were 19.05 mm in diameter and 6.35 mm thick.
- SHPB were made of 7075-T6 aluminum.
- Lead pulse shaper was 9.525 mm in diameter and 1.058 mm thick.
- Sampling was at 125 MHz with a period of 1ms.



Dynamic Tensile Strength

Dynamic Tensile Strength:

Mean: 15.77 MPa; Median: 15.18 MPa Standard Deviation: 3.60 MPa

Quasi-Static Tensile Strength:

2.2-4.4 MPa [8]

Weibull Analysis [9]:

$$p(x) = 1 - e^{-\left[\frac{(x-x_o)}{b}\right]^m}$$

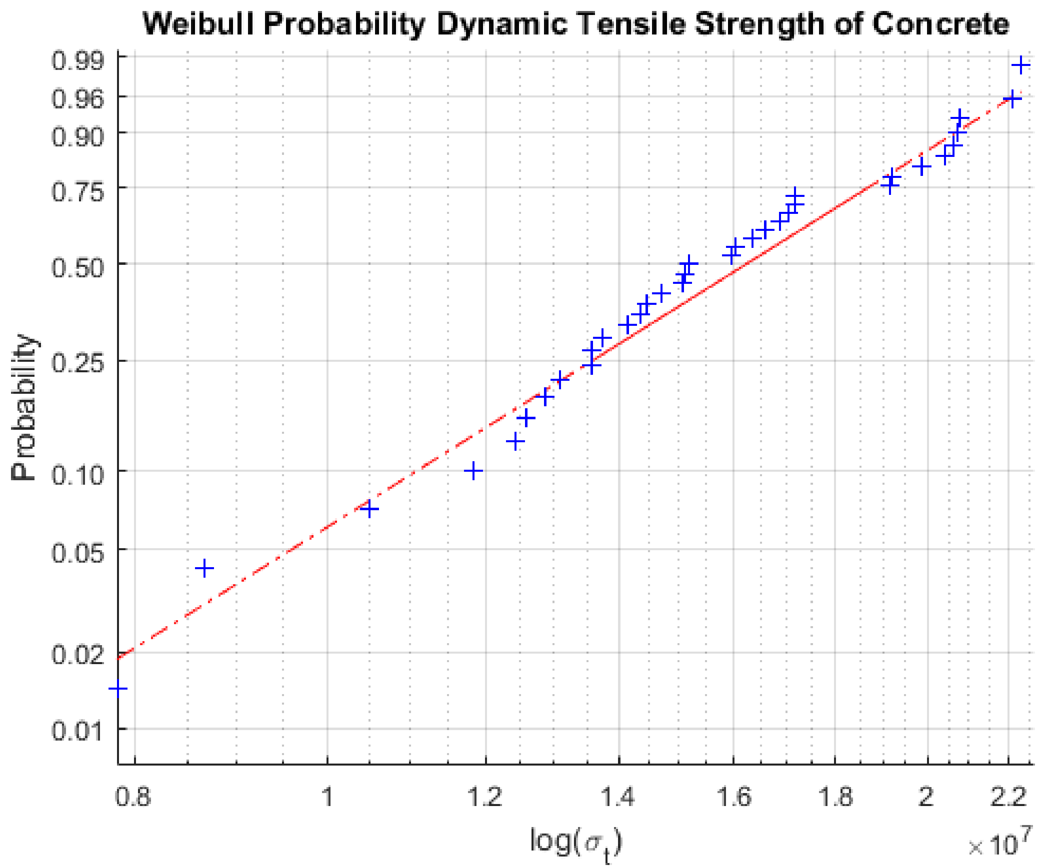
Where:

x_o = 7.84 MPa

b = 17.18 MPa

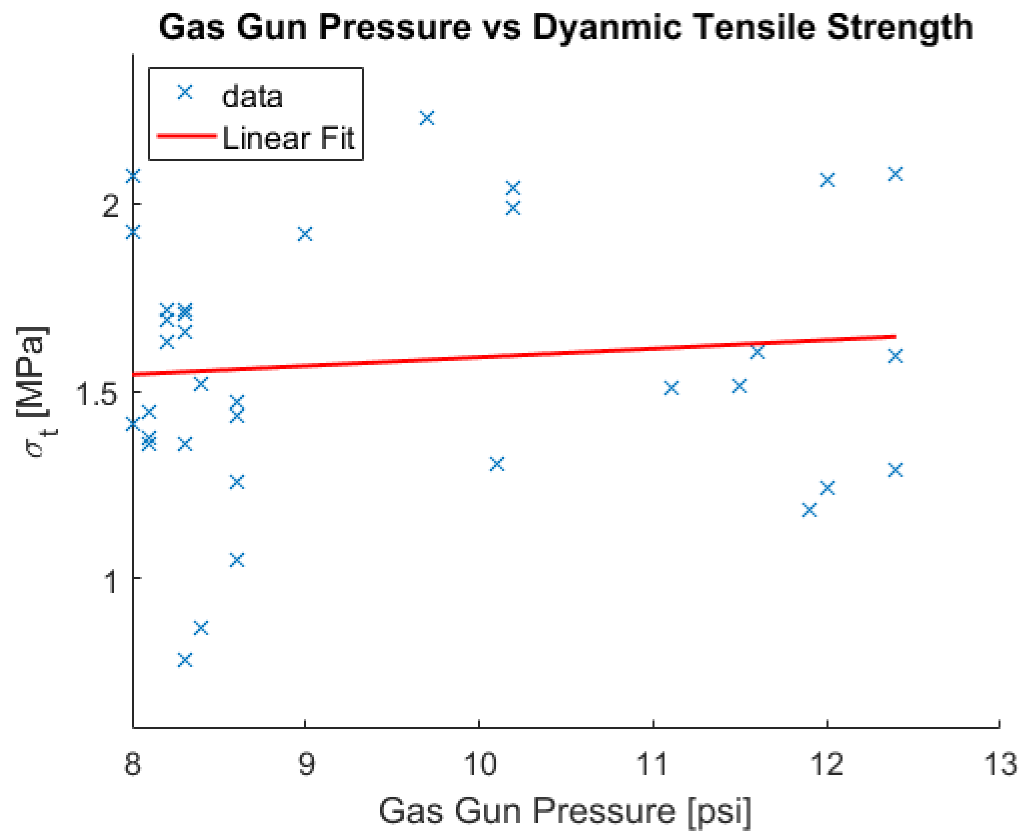
m = 4.9951

N = 35 specimens



Gas Gun Pressure and Tensile Strength

- Gas Gun Pressure and Strain Rate were expected to be correlated.
- No correlation was seen when looking at cumulative class data.
- Pulse shaping between groups could impact correlation.



Conclusions

- A positive correlation between strain rate and ultimate tensile strength was confirmed.
- Minimal to no correlation between gas gun pressure and strain rate.
- Weibull statistical analysis showed moderate variance of strength values.
- Further investigation of strain rate using a measured striker bar velocity would allow the relationship between strain rate and tensile strength to be better quantified.

Acknowledgements

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References

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[6] D. Frew, M. J. Forrestal, and W. Chen, "Pulse shaping techniques for testing brittle materials with a split Hopkinson pressure bar," Experimental Mechanics, vol. 42, pp. 93(106), 2002.

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[8] S. U. Pillai and D. Menon, Reinforced Concrete Design, Third Edition.

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