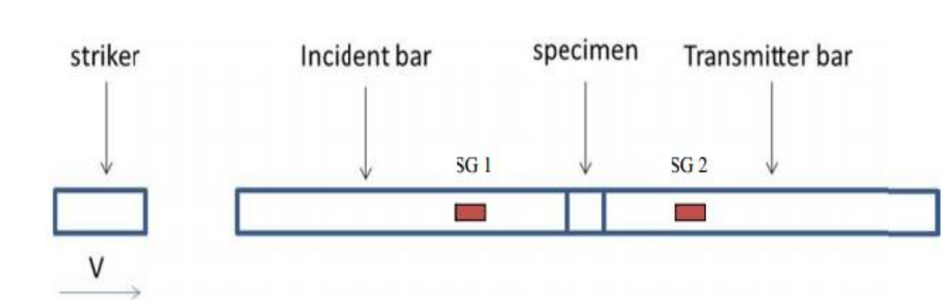
ISRAELI MINISTRY OF DEFENSE

ENERGY–BASED APPROACH FOR ASSESSMENT OF LOADING RATE EFFECT IN CONCRETE

Introduction

This study examined the effects of kinetic energy input during dynamic loading of concrete specimens. Two test methods could be used for such tests; with a drop hammer (DH) or with a Split Hopkinson Pressure Bar (SHPB). Both approaches were examined, and the results compared. The stress waves in these tests were investigated theoretically, and the role of the kinetic energy associated with such tests was examined. In addition, two Finite Elements models were developed in order to analyze the tests, and the results were compared with the theoretical findings. The conversion of the kinetic energy to strain energy was defined by using the theory of elastic waves. It was shown that part of the kinetic energy remained in the specimens, and the stress distribution along the specimen was not uniform. Finally, a short comparison of the SHPB and the drop-hammer test were presented.

Split Hopkinson Pressure Bar Device and Model



An illustration of SHPB

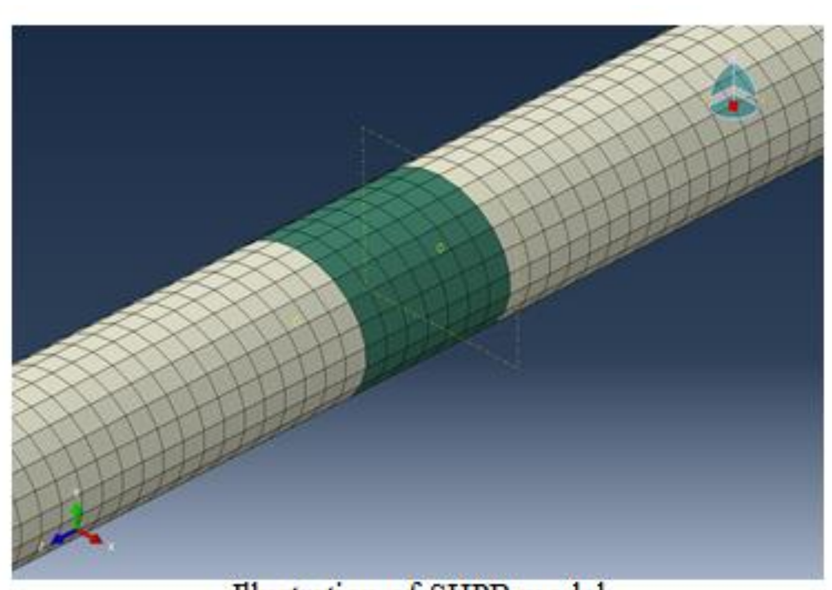
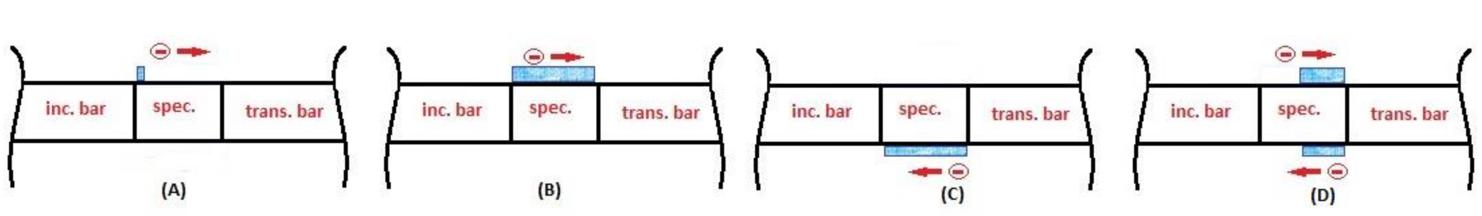


Illustration of SHPB model

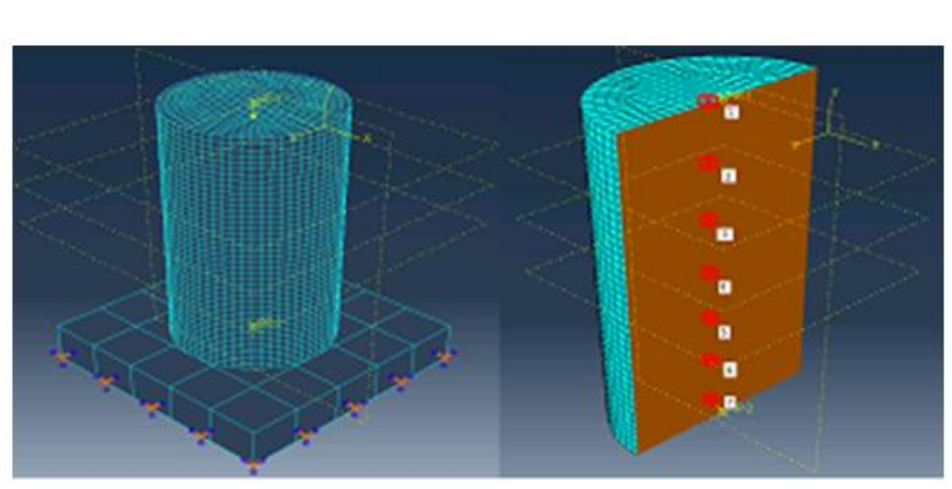
The roll of kinetic and strain energies during the wave propagation was investigated using a SHPB FEM model and 1D wave propagation theory. In addition, the non uniformity of strain distribution along the specimen was quantified. For this purpose, the model was loaded by a stress wave with a wave length equal to the specimen's length. four main interesting time points were predefined and are described below.



(A) "wave 1st face" - the stress wave reach the first face of the specimen. (B) "Wave 2nd face" - the stress wave reach the second face of the specimen. (C) "Reflected wave 1st face" – the reflected wave from the 2nd face reach the first face. (D) between time marks (B) and (C) - the reflected wave from the 2nd face reach the specimen's midspan (not marked on charts).

Drop – Hammer Test Device and Model

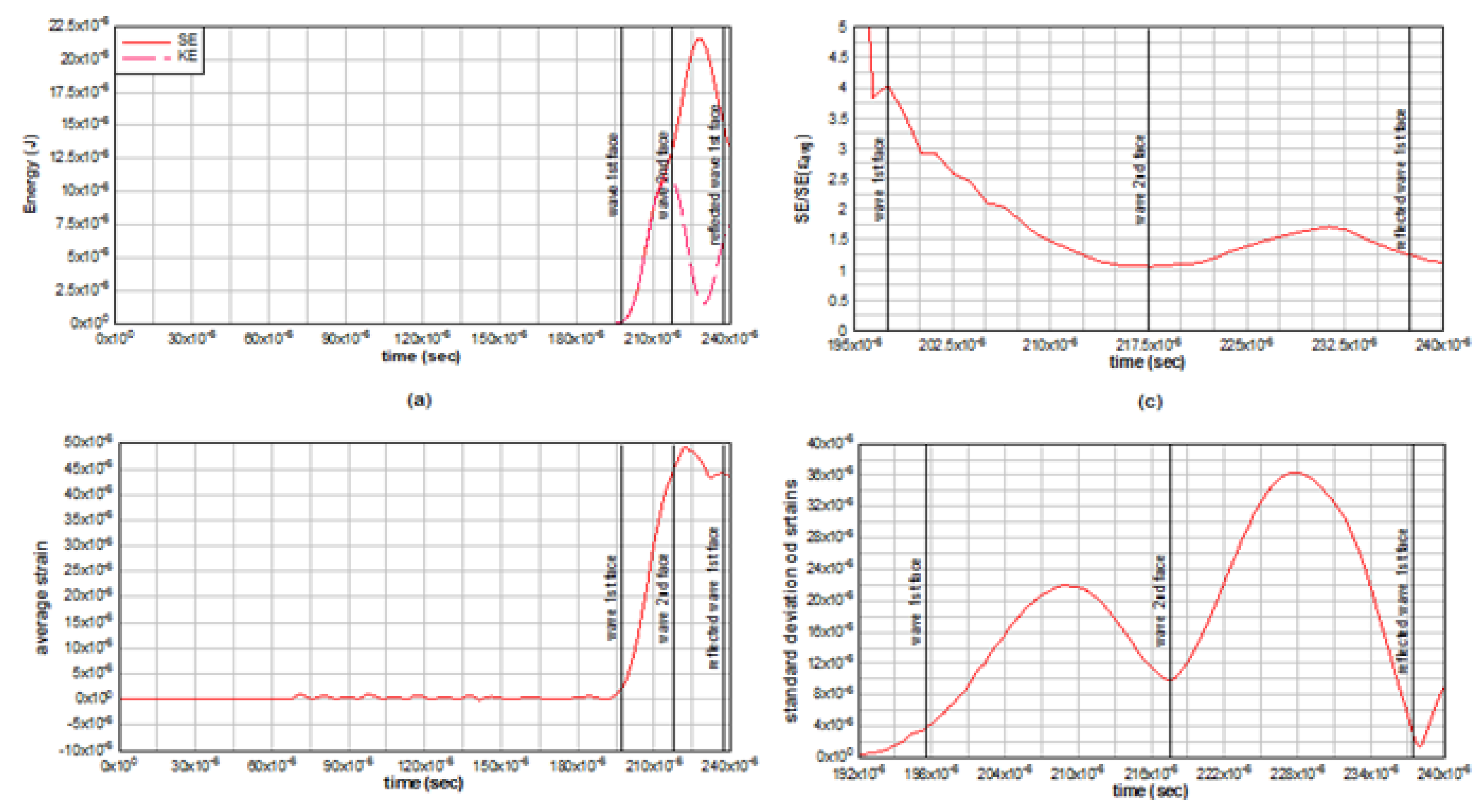
A typical drop –hammer and test specimen


FEM model of the drop-hammer test

- Load measurements are made by load-cells (LC) located at the bottom of the hammer.
- Strain measurements are made by strain-gauges (SG) located along the tested cylinder.
- A recorded stress, that was captured by the load cells during an experiment, was applied as a distributed load on the top of the FEM model's cylinder.
- The model results were taken from elements along the cylinder.

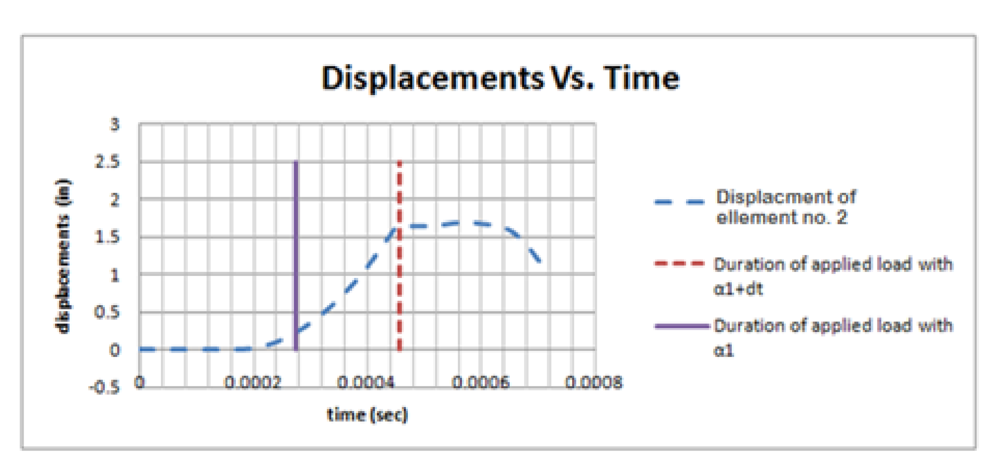
Results and conclusions

- During the reflections within the specimen, kinetic energy converted to strain energy. This process was accompanied with high non-uniformity of the strain distribution along the specimen.
- When the maximum strain energy was achieved, the kinetic energy was at a minimum, but not zero. This explained the velocity of the specimen fragments during the dynamic failure.
- The maximum strain energy did not correspond to the maximum strain in the specimen.

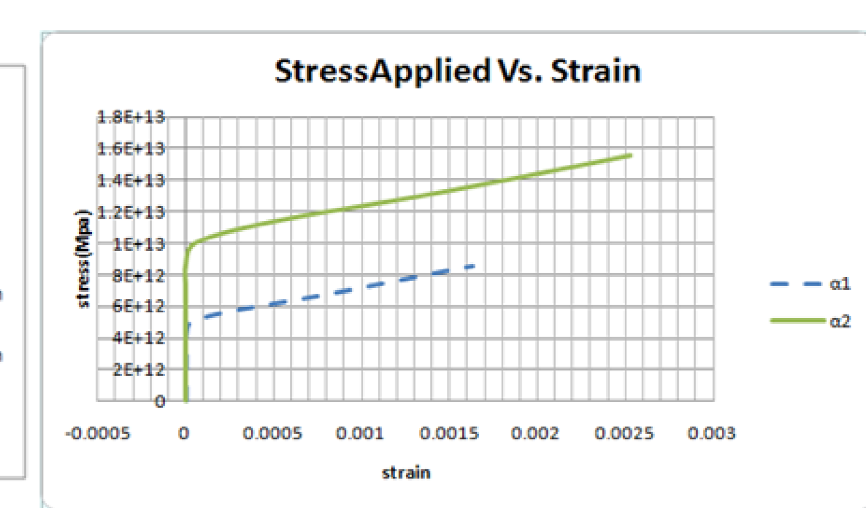


(a) Strain and kinetic energies at the specimen, (b) Average strain of the specimen (compression is positive), (c) SE/(G·ε²) vs. time, (d) Standard deviation of the strains in the specimen.

- During a stress-strain analysis, there is a time difference between the strain and corresponding stress, due to wave propagation.
- When plotting a stress-strain curve for different load rates, if the time differences are not taken into account, a false rate-effect will be observed. This is due to the fact that although the load rate increases, the time of the wave propagation stays the same.



The influence of the time difference on the correct correspond strain



A false rate-effect observation

Drop hammer test Vs. SHPB

	Drop Hammer test (DH)	SHPB	Consequences
Strain gauges (SG) location	On the specimen	On the bars	The strain readings of the cracked specimen in DH become unreliable.
Estimating the average stresses in the specimen	By a load cell (LC) located on the top of the specimen	By averaging the stresses on the two faces of the specimen	The results at the early stage of loading, when the stresses are not uniformly distributed along the specimen, are more accurate in SHPB
Stress-strain analysis	Stresses and strains are measured at two different locations (LC and SG)	Strains are measured on bars (SG) and average stresses are computed for the specimen	the time difference In DH and SHPB, due to wave propagation, between LC and SG readings , or SG and specimen, must be considered
The shape of each stress wave	Exponential decay with time	Rectangular	Must be considered when the wave propagation within the specimen is analyzed