THE NUMERICAL ROAD TO DETERMINATION OF FRACTURE ROLE ON IMPACTS AS SEISMIC SOURCES: FINITE-DISCRETE MODELING OF IMPACTS. E. Rougier[1], Z. Lei[1], B. Euser[1], Sharon Kedar[2], E.E. Knight[1], C.S. Larmat[1].
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Introduction: Recent developments in numerical methods and the increase of computing power make numerical modeling a promising way to investigate the physics of impacts and to provide answers to the outstanding question of seismic efficiency, i.e. the ratio of the generated seismic energy versus the total kinematic energy of the impactor available before the impact. The classical approach of establishing empirical laws has resulted in seismic efficiency estimates that vary from 10^{-2} to 10^{-5}. The number of parameters for these datasets is daunting, as the datasets used for these empirical laws encompass both explosions and impacts. As more datasets are collected in different terrestrial geologic settings, with more data expected to be recorded in the future for other planets (i.e., the hope of recording of an impact on Mars from InSight), the number of parameters is continuously increasing. Numerous factors have the potential to play an important role on seismic efficiency such as the diversity of properties displayed by both the impacted crust and the material of the impactor or the variety of processes occurring from the hydrodynamic regime existing near the source to the anelastic high-strain regime existing further to the regime where the shock waves transition into seismic energy, further adding to the impactors variables (e.g., momentum, velocity and shape) [1-3]. Our goal is to understand how much of the variability observed for seismic efficiency is due to the geology and properties of the ground.

Many numerical methods have been developed for modeling impacts; they differ in the choice of algorithm used to solve the differential equations as well as the constitutive equations considered to describe the material response. The latter are commonly divided into two parts, one governing the material's bulk response(equation of state), and the other governing the response to the deviatoric stresses (e.g., [4]). Pierazzo et al. [4] performed a benchmarking and validation exercise and showed that the discrepancy between results provided by different hydrocodes is about 10 to 20%, which is similar to the discrepancy between codes and experiments. These proposed cases were chosen to be either impacts in water or in aluminum alloys because modeling impact in geologic materials, such as rocks and soils, is still a major challenge. One major difficulty with these materials is the validation and benchmarking of material models, in addition to accounting for porosity and the disposition of geologic materials to undergo fragmentation. The modeling community has currently proposed some solutions: Güldemeister & Wünnemann [5] performed modeling for impacts in Mars soil and found seismic efficiencies that are roughly consistent with the value of 5.10^{-4} used by Teanby et al. [6] for estimating the number of impact events to be recorded by the Mars lander InSight.

Methods: We have been developing a hydrodynamic simulation code known as the Hybrid Optimization Software Suite (HOSS) which is an implementation of the combined Finite-Discrete Element Method(FDEM) that merges conituum solutions devised via the Finite Element Method for the calculation of stresses as a function of deformation with those derived under the Discrete Element Method for the resolution of fracture, fragmentation and contact interaction [7-9].Our fracture model uses a macroscopic description of thousands of particles, reducing the memory requirement while maintaining the fidelity to observe fragmentation processes in a variety of materials. This approach has been validated with laboratory and field-scale data generated by the Source Physics Experiment (SPE), a series of explosions performed in granite and tuff [10]. Large deformation in elements is also now possible thanks to a new methodology that prevents element instability under extreme loading conditions,allowing for proper estimation of the materials response in these high-strain-rate regimes.We use HOSS to model aluminum test cases proposed by Pierazzo et al. [4] and to laboratory experiments provided by JPL.

Benchmarking Results:

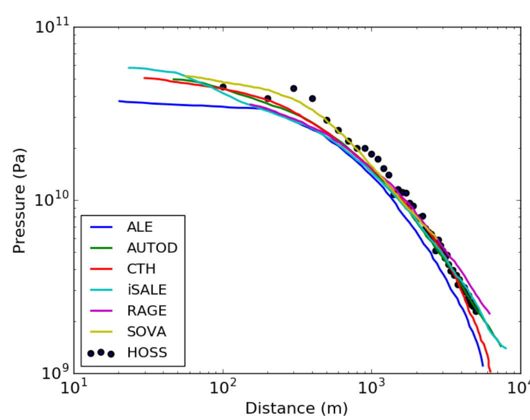

Figure 1: Pressure decay downward from the impact point of a 1km diameter aluminum sphere impacting an aluminum body. The results from HOSS are compared to a number of different numerical methods.

Figure 1 shows the shock pressure decay produced by HOSS for a 5 km/s impact of aluminum on aluminum.

As illustrated by Fig. 1, the pressure decay produced by HOSS compares favorably to the benchmarking results published by Pierazzo et al. [4], providing confidence that HOSS is accurately capturing the material response.

Expected Validation Results: In 2012, a series of 23 high-velocity seismically recorded impact experiments were conducted in a highly controlled environment at the NASA Ames Vertical Gun Range (AVGR) facility by JPL in collaboration with Purdue University. In these experiments, projectiles were shot (impact speeds ranging from 0.95 km/s to 5.82 km/s) towards an unconsolidated heap of pumice and sand, which served as proxies for Moon soil under highly controlled testing conditions. These experiments are a great opportunity for validation thanks to high-sampling-rate (100 kHz) photographic data, dense and high-rate-sampling seismic data and crater morphology measurements. We expect validation of our hydrodynamic modeling by comparing the modeling results to these experimental results.

References:

[1] H. J. Melosh (1989) New York, Oxford University Press.

[2] J. E. Richardson, H. J. Melosh, N. A. Artemeiva, E. Pierazzo (2005). *Space Science Reviews*. **117**, 241–267.

[3] J. E. Richardson, H. J. Melosh, R. J. Greenberg, D. P. O'Brien (2005) *Icarus*. **179**, 325–349 (2005).

[4] E. Pierazzo *et al.*, (2008), vol. 43, pp. 1917–1938.

[5] N. Güldemeister, K. Wünnemann (2017) **296**, 15–27 (2017).

[6] N. A. Teanby (2015) *Icarus*. **256**, 49–62 (2015).

[7] A. Munjiza (2004) John Wiley & Sons, Ltd, Chichester, UK.

[8] Munjiza A, Knight EE, Rougier (2011) John Wiley & Sons, Ltd, doi:10.1002/9781119971160

[9] Munjiza A, Rougier E, Knight EE (2015), John Wiley & Son Ltd.

[10] C. M. Snelson *et al* (2013) *Eos Trans. AGU*. **94**, 237–239.