IMPACT HYDROCODE BENCHMARK AND VALIDATION PROJECT: IMPACTS INTO COHESIONLESS SOIL.

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Introduction: Computer models offer a powerful tool for understanding the mechanics of impact crater formation. A new set of validation tests has been carried out as part of a collective validation and benchmarking effort. The first set of benchmark and validation tests involved strenghtless and metal targets [1]. Here we present initial results of validation tests of a polyethylene cylinder impacting dry sand at 1G and 464G.

The Validation and Benchmarking Project: The Validation and Benchmarking Project brings together a collective expertise in numerical modeling of impact and explosion events, continuum mechanics and computational physics in an effort to enhance, compare, validate and benchmark the computer tools ("shock physics codes") used to model solar system impact events. The benchmark component identifies a set of hypothetical explosive and impact events of varying complexity to compare the different numerical and physical models employed in the codes. The validation component defines a set of well-documented laboratory and field experiments over a wide range of event sizes, geological materials and problem types as type-cases that must be reproduced in detailed and systematic code simulations. Laboratory tests are useful because they are conducted under well-known conditions, although scale may influence the results. Field explosion tests are complementary in that they provide important data over a much larger range of sizes. A set of experimental tests were selected to encompass as many observables as possible and to sample a wide a range of experimental conditions. They include tests in simple materials such as water and metal, and in more complex materials such as soil and rock. The final objective of this study is to provide the test informations and results to the scientific community to help prevent the incorrect and misinformed use of the codes and to provide a set of rules and test cases to follow to properly benchmark and validate hydrocodes to come.

Impact Hydrocodes: Shock physics codes were originally developed for hydrodynamic phenomena, but most have been extended to include material strength effects in diverse material types including metals and geological materials., They all contain the fundamental physics needed to model high-energy impact/explosion events, and, with appropriate material models, can be used to model general impact/explosion cratering. The hydrocodes currently used in this validation project include: AUTODYN [3], CTH [4], RAGE [5], iSALE [6,7], ZEUSMP2 [8].

Impacts in Dry Sand: The new tests aim at validating constitutive models used in shock physics codes for a relatively simple (cohesionless) dry soil. We selected two experiments carried out at the Boeing laboratory [9-11]. The first is an impact experiment on a geotechnic centrifuge, with a centripetal acceleration of 464G, where G is Earth's gravity (9.8 m/s^2). The second is a normal laboratory impact experiment, at 1G.

The centrifuge tests reproduce the behavior of large-scale events at typical laboratory subscales. A small-scale experiment conduced at n-times the normal gravity level will correctly reproduce an event that is n-times larger in each linear dimension [9] and a factor n^3 larger than the actual impact energy. In this case, the 464G experiment corresponds to a larg-scale experiment with a simulated energy of 52 tons of TNT.

In both experiments, Flintshot sand (ρ=1.8 g/cm^3) was placed in aluminum cylindrical containers at or near its maximum packing density. The impactor, a polyethylene cylinder 12.2mm in diameter and height had a mass of about 1.35 g (0.94 g/cm^3), and an impact velocity of 1.81km/s in the 464G experiment and 1.85 km/s in the 1G experiment. Diagnostics measured in the experiments were the final crater profile for both experiments. A quarter-space experiment [e.g., see 1] similar to the 1G case (slightly higher impact velocity, 1.94 km/s) had been carried out to measure experimentally crater growth and ejection velocities. In that test a half crater is formed against a transparent window so that the evolving crater profile can be observed. Since the same impactor is creating only half a crater, if there are no energy lossed into the window, then it is the same as a complete crater forming from twice the impactor mass.

Validation Results: Simulations are carried out assuming a half space vertical impact simulation. Fixed input conditions include the projectile size/shape, mass and impact velocity/angle, and target material (dry sand). Technical details (including resolution), material models and relative parameters for the materials were chosen by individual modelers. This is an important difference from benchmark testing, which focuses on comparing code performances given well-constrained simple tests. One important component of validation testing consists in testing the modelers identification and use of the proper material models. One of our goals in this context is to verify how modelers' choices can affect the output results.

The material models for a dry sand typically include an equation of state for the high pressure response, a porous crush model and a failure envelope of the Mohr-Coulomb type. Differences in choice of model and parameters can substantially change the nature of the outcome. It is easy to adjust any single gross features such as crater volume or final radius to any desired value just by changing some strength values. And any strength model, even non-appropriate ones, such as the von Mises model used for metals, can do that. But the details such as crater dynamic evolution, shape and ejecta characteristics are much harder to match. A summary of the choices made by the different contributors to this study will be presented at the conference.

1G (Laboratory) test: The 1G impact into dry sand provides the most diagnostics when combined with the quarter space experiment. Besides the final crater characteristics, transient crater profiles in the quarter spce test have been recorded at times ranging from 0.8 to about 16 ms. Figure 1 shows crater profiles at about 5ms after impact. At this early time the iSALE and AUTODYN results match follow the experimental profle well. However the experimental data is for the quarter spece test, so those calculations should be scaled up to an impactor of twice the mass, predicted to be a factor of about 1.25 in crater dimensions. The CTH calculation used twice the mass, so scaling is not necessary. Its results are slightly larger than the experiment. That may be because of energy losses into the observing window in the experiment.

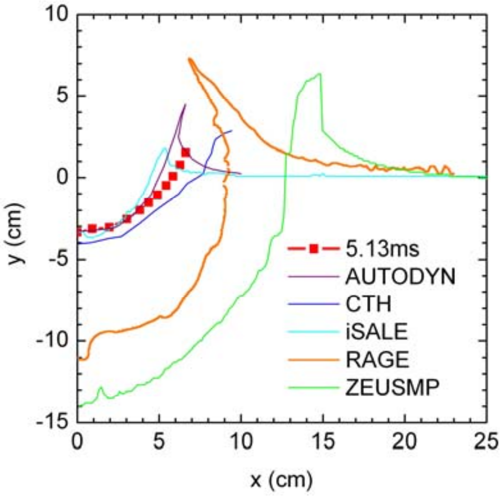

Fig. 1: Crater profile after about 5ms (experimental profile in red) for the 1G impact into dry

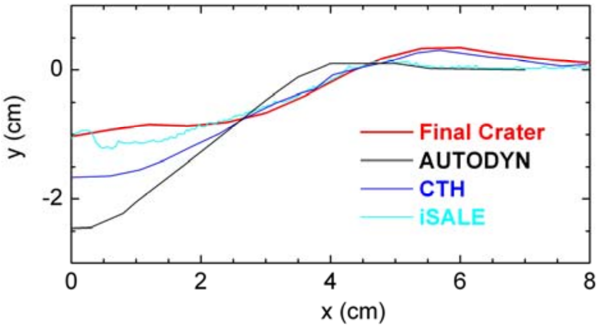

Fig. 2: Final crater profile (experimental profile in red) for the 464G impact into dry sand.

Both RAGE and ZEUSMP appear to have difficulties in modeling dry sand, clearly overestimating crater size. That is undoubtedly a problem with the material strength modeling. While final crater profiles have not been reached for all codes yet, initial inspection of final crater profiles for CTH and iSALE indicate a tendency of shock physics codes to over estimate crater depth, while closely matching crater radius.

464G (centrifuge) test: At 464 times the normal gravity, the crater forms much more quickly. Final crater profiles for the various simulations are compared to the experimentally measured profile in Figure 2. No RAGE and ZEUSMP final profiles are available at this time, due to the limitations of the material model used (as described above). While AUTODYN underestimates the crater radius, the CTH and iSALE results are both well within uncertainties due to the uncertain material modeling.

Further results of our first validation test will be presented at the meeting.

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