**Validating Explosion Craters from Underground Detonations.** S.F. Henderson and W.K. Caldwell, Los Alamos National Laboratory, Los Alamos, NM 87545, sebastian@lanl.gov

**Introduction:** Sedan Crater is the largest human-made crater on Earth. Part of Operation Plowshare, the underground detonation which formed the crater was designed to explore the use of nuclear explosive devices (NEDs) for civilian and infrastructure applications. The NED from the Sedan test was buried 192 m below the surface in Nevada. The geologic material of the test site was alluvium. The resulting crater had a diameter of 372 m and a depth of 98 m. The lip height varied from 4 m to 30 m, with an average lip height of 13 m [1]. Figure 1 shows an image of the Sedan crater.

Figure 1: Image of Sedan crater, the result of an underground nuclear test. Image credit: National Nuclear Security Administration Nevada Site Office Photo Library, NF-12187.

Crater modeling is important for predicting measurements of craters formed from impacts and explosions, especially because these events often exceed experimental capabilities. The Los Alamos National Laboratory (LANL) hydrocode FLAG, previously shown to be an effective method of modeling crater formation [2], was used to model the excavation of Sedan Crater. In this work, we demonstrate that FLAG simulations of the Sedan event have good agreement with test data, including crater shape and size, the height of the soil mound prior to rupture, and the time at which the soil mound ruptured.

**Methods:** We use the FLAG hydrocode, developed and maintained by LANL, to model the Sedan event [3]. FLAG is a finite-volume arbitrary Lagrangian-Eulerian (ALE) code with modeling capabilities in 1–3 spatial dimensions [3,4]. FLAG has the ability to model both fluids and solids and can incorporate a variety of equations of state (EOS) and material models [3,4].

**Validation, Preliminary Results:** We first modeled the detonation in 2D axisymmetric geometry. We ran a strengthless simulation of the explosion as a Sedov problem, initializing a spherical region of the soil with the equivalent energy present in the Sedan test (~100 kilotons). We selected the high-energy region to be 192 m under the surface of the alluvium, consistent with the depth of burial of the NED. We chose a tabular equation of state for the soil from the SESAME database, developed and maintained by LANL and informed by experimental data [5]. Because explosive simulations can introduce vorticity into a Lagrangian mesh, we chose an ALE relaxer based on cell geometry: the mesh was relaxed locally in and around cells with internal angles measuring 15º or less to prevent mesh tangling. Figure 2 shows this strengthless simulation at 3.6 s colored by density. As expected, the strengthless simulation resulted in a larger crater than the actual Sedan event.

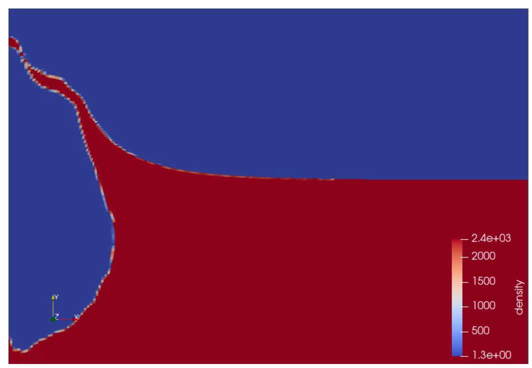


Figure 2: Screen capture of the strengthless simulation at 3.6 s, colored by density. At this time, the surface of the alluvium breaks.

**Validation, Ongoing Work:** We are currently modeling Sedan as a detonation into solid alluvium with constant yield stress, which considers the material strength of the alluvium to determine whether additional modeling tools, such as more robust strength, fracture, and damage models, are needed to accurately capture the rupture of the soil mound. Once 2D simulations provide sufficient matches to the Sedan event, we will move to 3D models. Because 3D models are more computationally expensive and take considerable resources, our 2D simulations will serve as scoping studies to rule out modeling choices that are unlikely to yield desired results in 3D.

**Future Work:** Volcanic crater formation includes many similarities to underground detonations. Craters from nuclear explosions share similar symmetry and motivate the description of the volcanic crater evolution by the superposition of several idealized blasts. In reality, volcanic crater formation can be more complicated because of this multi-explosion phenomenon. An asymmetrical energy source is often considered when modeling volcanic craters as well [6]. Laboratory experiments at the University of Buffalo included both single and multi-blast craters as volcanic crater analogs [7]. We plan to model these experiments as further validation for FLAG's capabilities of modeling explosive craters.

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