Oral presentation | Fluid-structure interaction
Fluid-structure interaction-III
Mon. Jul 15, 2024 4:30 PM - 6:30 PM Room A

[3-A-01] Blast Wave Propagation Through Debris Cloud

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Blast Wave Propagation Through Debris Cloud

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Overview

- **Objective: Understand the physical mechanisms controlling blast wave energy losses when propagating through a debris cloud**
- **Approach: testing and numerical modeling**
- **Investigate effects of**
  - **Debris: pebbles vs. dust**
  - **Debris cloud weight**
  - **Debris cloud porosity**
  - **Debris positioning**

FEFLO: The flow solver

- Adaptive, unstructured grids (triangles/tetrahedra)
- Compressible & incompressible Flows
- Inviscid, laminar & turbulent Flow
- Several turbulence models (MILES, Smagorisnky, Baldwin-Lomax, Spalart-Allmaras, K-Epsilon, etc)
- Explicit and implicit time stepping
- EOS: Real air, water (Tate), Sesame, polynomials, tables
- State-of-the-art shock capturing numerical schemes
  - (Roe, FCT, HLLC, ENO, WENO, DG…..)
- Body-fitted ALE or embedded for moving bodies/change of topology
- Edge-based FE data structure
- Finite rate reaction: detonation, afterburning, agents/simulants
- Infinite rate reaction model
- JWL+Miller after-burn models
- Particles as a dilute phase
  - Exchange of mass/momentum/energy with flow
- Extensive benchmarking and validation
- Live codes; FEMAP, FEFLO and ASICSD continuously evolved

Test and Simulation Plan

Test 3.1: Base case, no pebbles
Test 3.2: Two cylinders, Pebbles; 16.4lbs and 26.8lbs
Test 3.3: Two cylinders, Sand, 15.4 and 32.3lbs
Test 3.4: repeat of 3.2
Test 3.5: Single Cylinder, Pebbles, 50.7lbs
Test 3.6: Bottom: two cylinders, thin, Sand, 8.89lbs,
Top: two cylinders Pebbles, 52.5lbs
Test 3.7: Two cylinders, Pebbles, 95.1lbs

All tests have identical charge and top/bottom heavy pebble caps

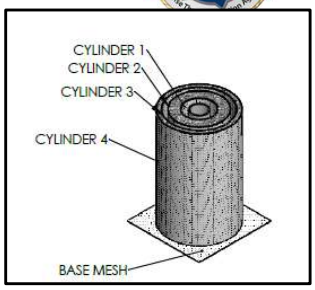
Test Details

Two types of debris were used

- Sand: Passes #100 sieve (150μm) but does not pass a #200 sieve (75μm) => 75μm<D< 150μm
- Gravel: Passes ¾ in. sieve but does not pass a 5/8 in. sieve (8.0mm to 9.52mm in radius)

Dust

Gravel



Explosive within Cylinder 1
Debris between cylinders 1 and 2;
Airgap between 2 and 3; and
debris between cylinders 3 and 4

In this presentation, the debris constitute an open cylinders, but will be referred to as cylinders.

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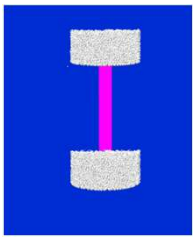
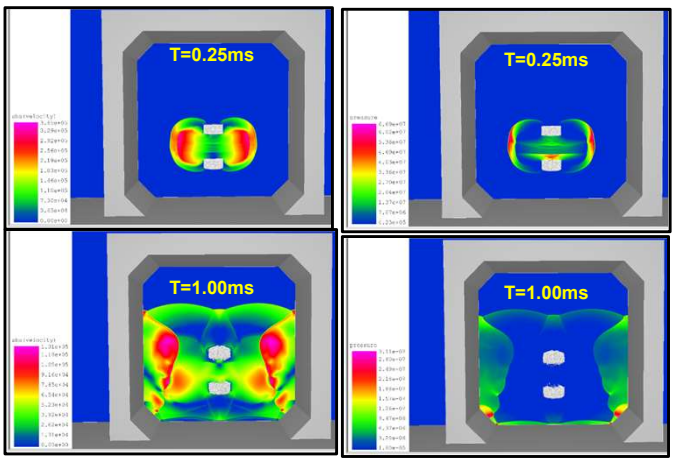
Test 3.1; Bare Charge

Base test; no debris, only top/bottom end caps

Velocity and Pressure on a plane cut

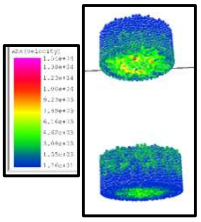


Initial set-up;
Density Contours; t=0.0



Velocity Contours

Pressure Contours



Pebbles velocity; 0.250ms

Blast wave propagation with no debris cloud. Blockage on top and bottom

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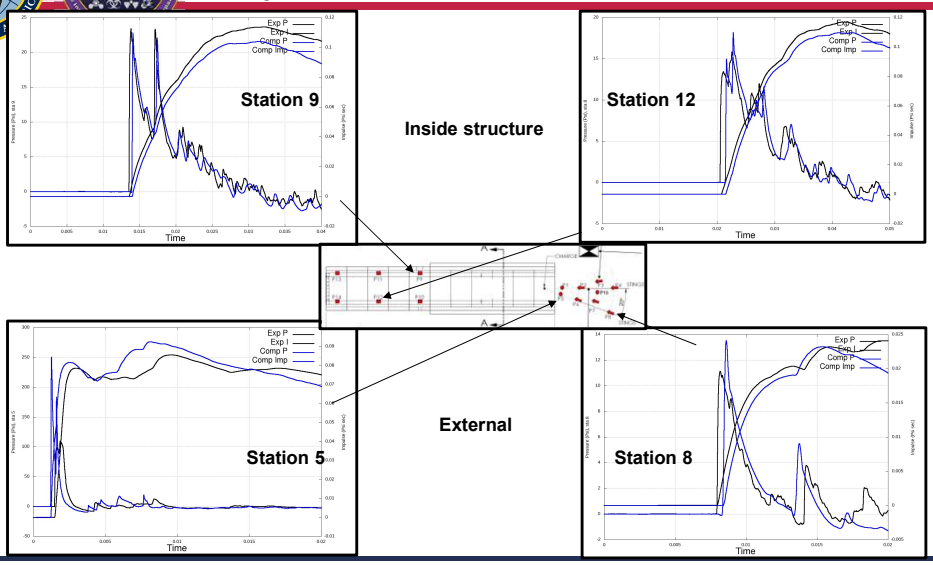
Test 3.1; Bare Charge

Comparison of Station time histories



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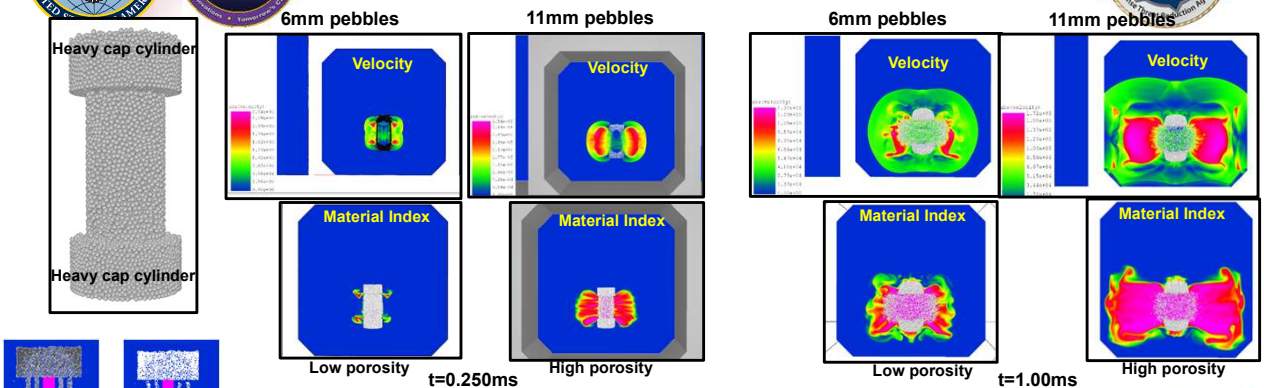
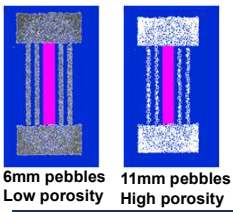
Test 3.2; Pebbles, Two cylinders; 16.4lbs and 26.8lbs

Velocity and Material Index on a plane cut;





A clear indication of blast wave energy transmission is the blast front location at 1.0ms

6mm pebbles =>low porosity (densely packed); 11mm pebbles => high porosity (loosely packed)
Modeled 6mm, 9mm (test) and 11mm; total pebbles weight identical for all three.
Larger pebbles have higher porosity, and hence less effective in containing the detonation products => faster detonation products escape leading to slower pebbles, less energy spent on accelerating the pebbles and higher impulse and pressure on the target.

6mm pebbles

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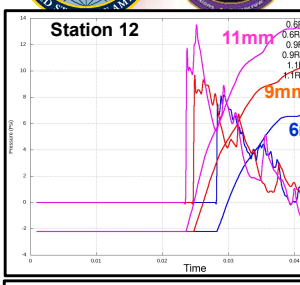
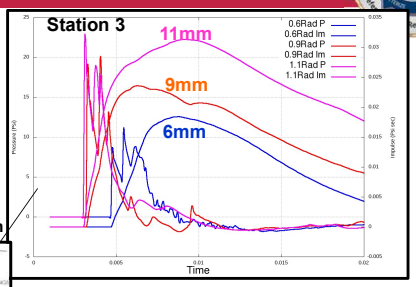
Test 3.2; Pebbles, Two Cylinders; Porosity effect

Comparison of Pressure and Impulse

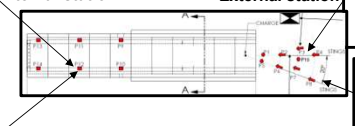


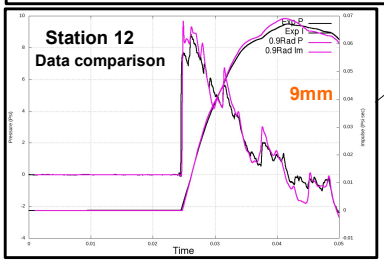
All pebbles have the same weight.



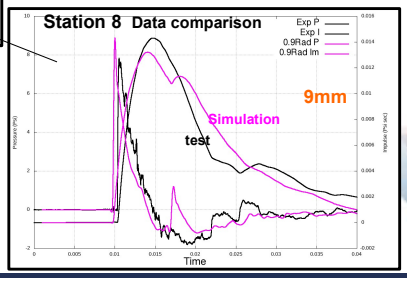
Internal station

External station





Larger pebbles have higher porosity, and hence less effective in containing the detonation products => faster detonation products escape leading to slower pebbles, less energy spent on accelerating the pebbles and higher impulse and pressure on the target.



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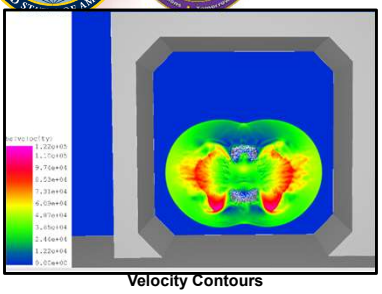
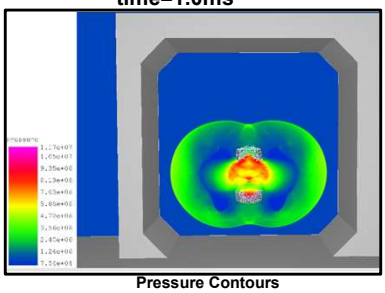
Test 3.3; Two cylinders, Sand; 15.4 and 32.3lbs

Velocity, Pressure and Material Index on a plane cut; 1.0ms

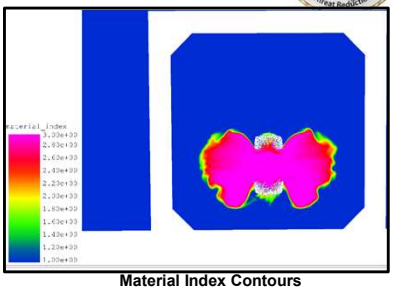
time=1.0ms



Velocity Contours

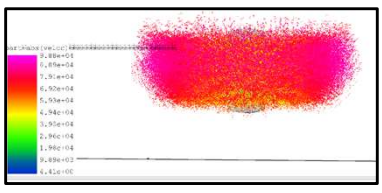


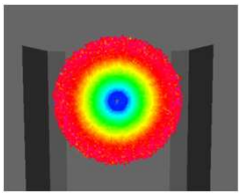
Pressure Contours

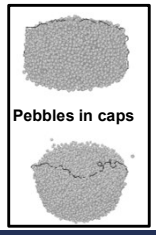


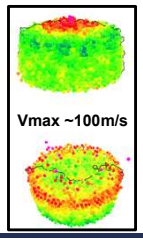
Material Index Contours

Sand velocity at 1.0ms; side and top views









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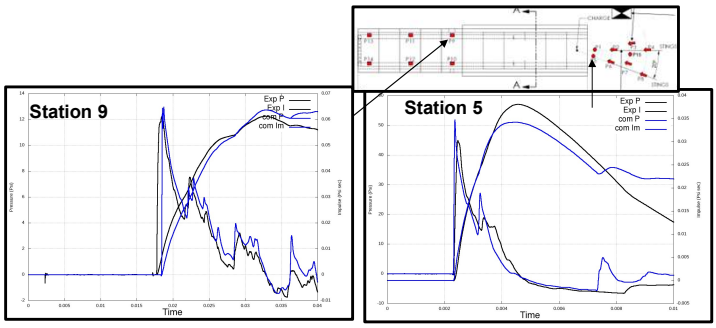
JB1

Test 3.3; Two Sand Cylinders; 15.4 and 32.3lbs

Video: Early time Pressure contours + Sand



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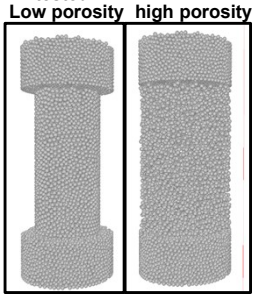
Test 3.5, Pebbles, Single Cylinder, 50.7lbs

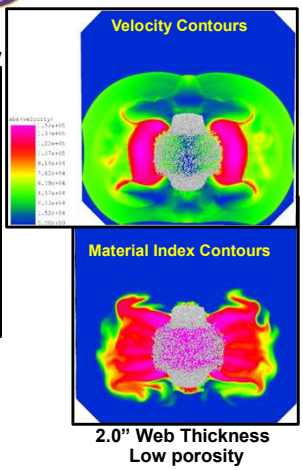
At 1.0ms, Velocity, Material Index on a plane cut, and Pebbles Velocity

Notice difference in blast front location

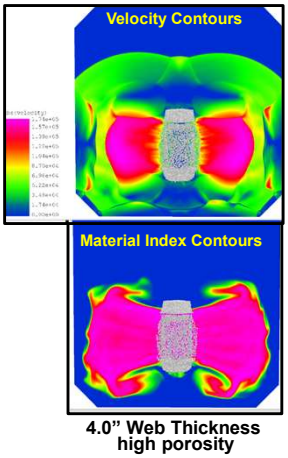
tested
Low porosity high porosity



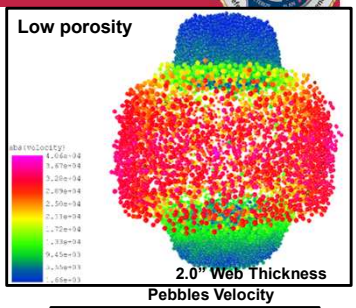
Same exact Pebbles weight
and diameter,
Cylinder web 2.0" => 4.0"
➔ Increased Porosity



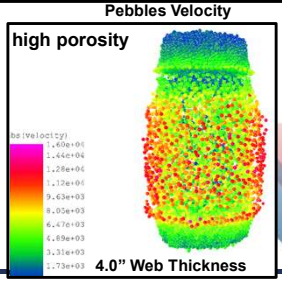
2.0" Web Thickness
Low porosity



4.0" Web Thickness
high porosity



Pebbles Velocity



The blast propagates faster through the high-porosity pebbles => lower pebble velocity and KE, and lower blast wave energy losses

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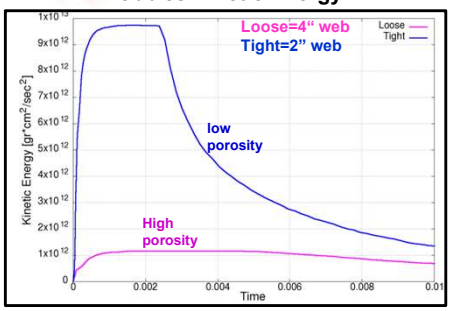
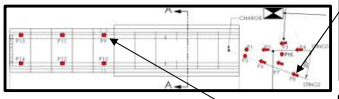
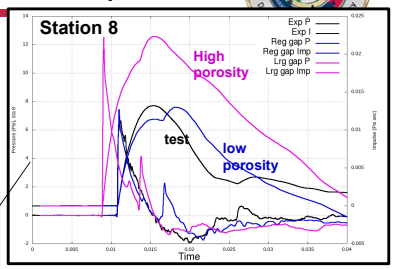
Test 3.5; Pebbles, Single Cylinder; 50.7lb

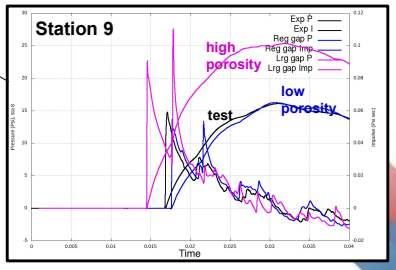
Comparison of Pebbles Kinetic Energy for 2" and 4"web; pressures

Pebbles Kinetic Energy







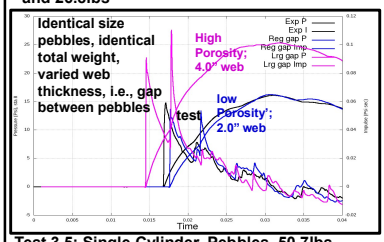


- Pebbles are taken out when impacting the tunnel walls
- Higher porosity decreased pebbles KE by ~order of magnitude

High porosity => shock propagates faster through pebbles => less work done on pebbles (hence, lower pebble velocity and KE) ➔earlier blast wave arrival to target and higher pressures and impulses

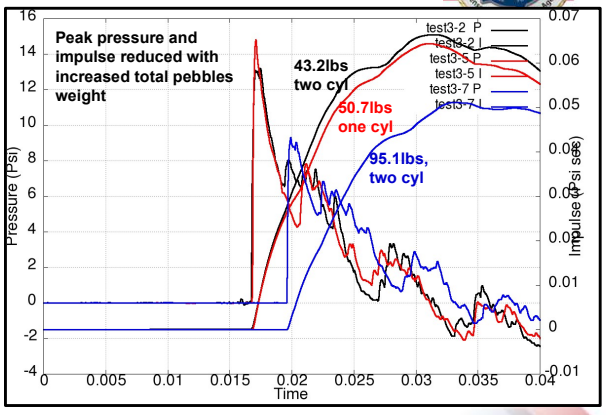
Blast Wave Propagation Dependence on Porosity and Weight; station 9

Test 3.2: Pebbles in two cylinders; 16.4lbs and 26.8lbs



Test 3.5: Single Cylinder, Pebbles, 50.7lbs

High porosity allows faster blast wave propagation through, and hence earlier TOA, and higher peak pressure and impulse



Test 3.2: Two cylinders, Pebbles; 16.4lbs and 26.8lbs
Test 3.5: Single Cylinder, Pebbles, 50.7lbs
Test 3.7: Two cylinders, Pebbles, 95.1lbs
Also: one vs two cylinders, about same weight
Test 3.2: Two cylinders, Pebbles; 16.4lbs and 26.8lbs
Test 3.5: Single Cylinder, Pebbles, 50.7lbs

Summary

- Investigated energy loss dependence on material density, porosity, total weight and geometry
- Numerical predictions were in excellent agreement with the data
- Pound-per-pound, dust depleted more energy than pebbles
- Energy load at tunnel stations depended on
  - 1. Large gaps for large pebbles allowed easier airblast transmission
  - 2. Containment duration affected both blast energy transmission and detonation products afterburning
  - 3. Sand contained better than pebbles and further reduced/delayed afterburning

Acknowledgements:
CPU time was generously contributed by the HPCMP and ARL via early access to Jean.
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All simulations were conducted using 32 nodes. Typical run duration ~96 hours (~300K CPU hours/run).