On the Role of Modeling Dust Production by Fragmenting Warheads in Storage Facilities

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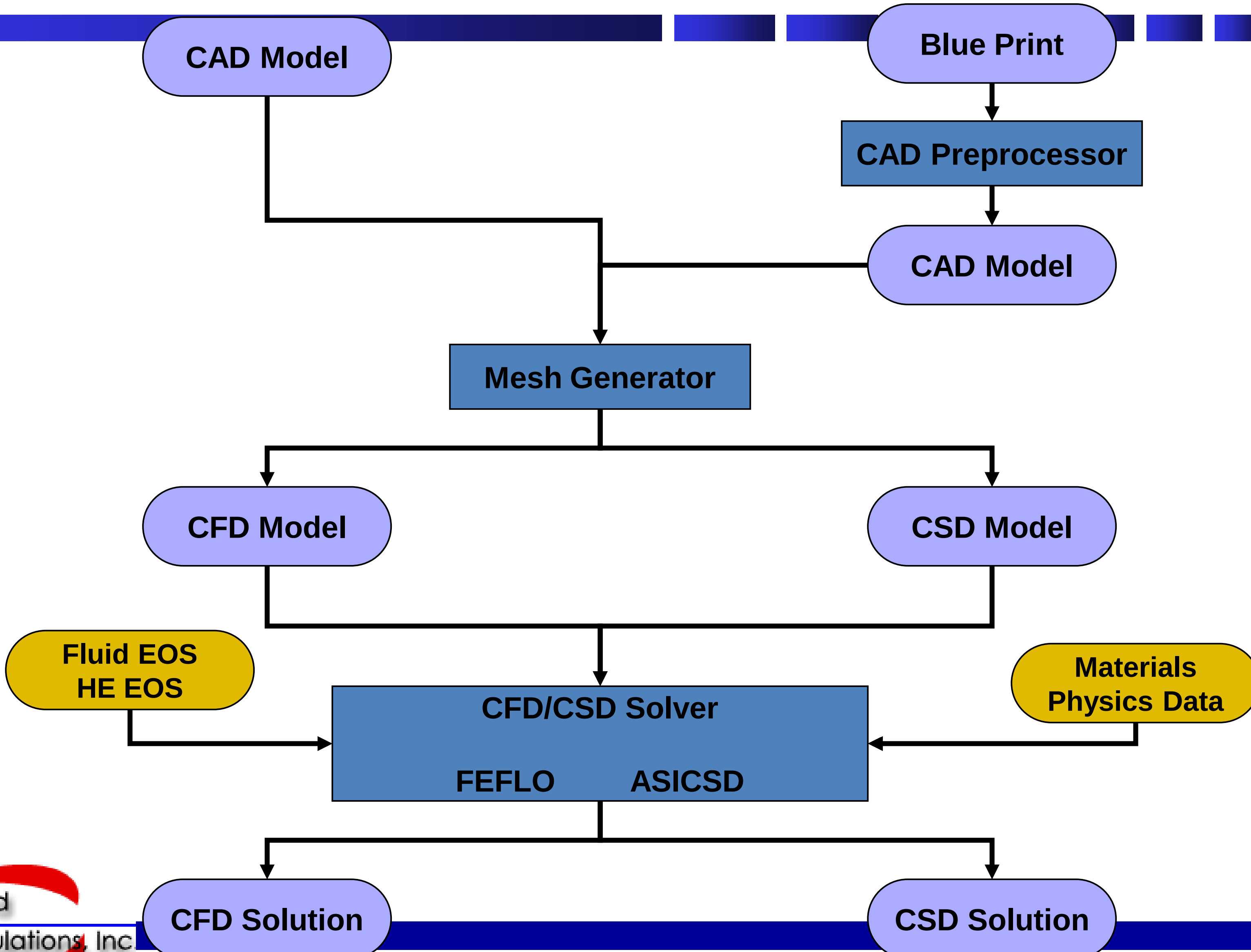
Outline

- Motivation
- The Coupled CFD/CSD Methodology Description
- The test facility
- Initial simulations of weapon detonation and fragmentation with no dust production/modeling included
- Test results observations
- Comparison of results from simulations including dust modeling
- Lessons learned and conclusions

Fluid/Structure Coupling Methodology



FEFLO, flow solver

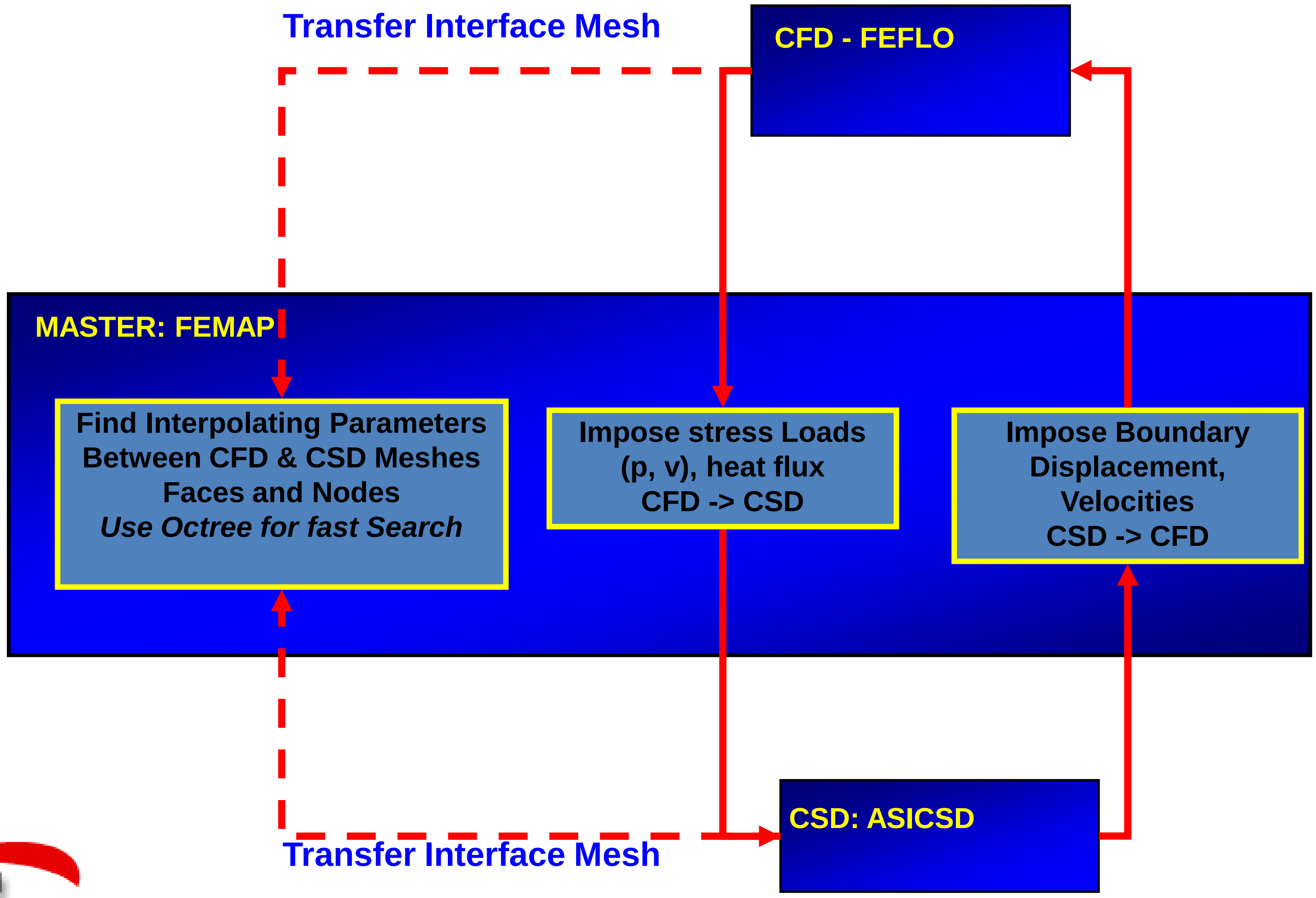
- Adaptive, unstructured grids (triangles/tetrahedra)
- Compressible & incompressible Flows
- Inviscid, laminar & turbulent Flow
- Several turbulence models (MILES, Smagorisnky, Baldwin-Lomax, Spalart-Allmaras, K-Epsilon)
- Explicit and implicit time stepping
- EOS: Real air, water (Tate), Sesame, polynomials, 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
- Kinetic combustion modeling of afterburning
- JWL (HE, non-ideal HE), Miller after-burn models, Cheetah
- *Particles as a dilute phase*
  - Exchange of mass/momentum/energy with flow
- Extensive benchmarking and validation
- International group of users (in many disciplines)

Coupled CFD and CSD: ASICSD

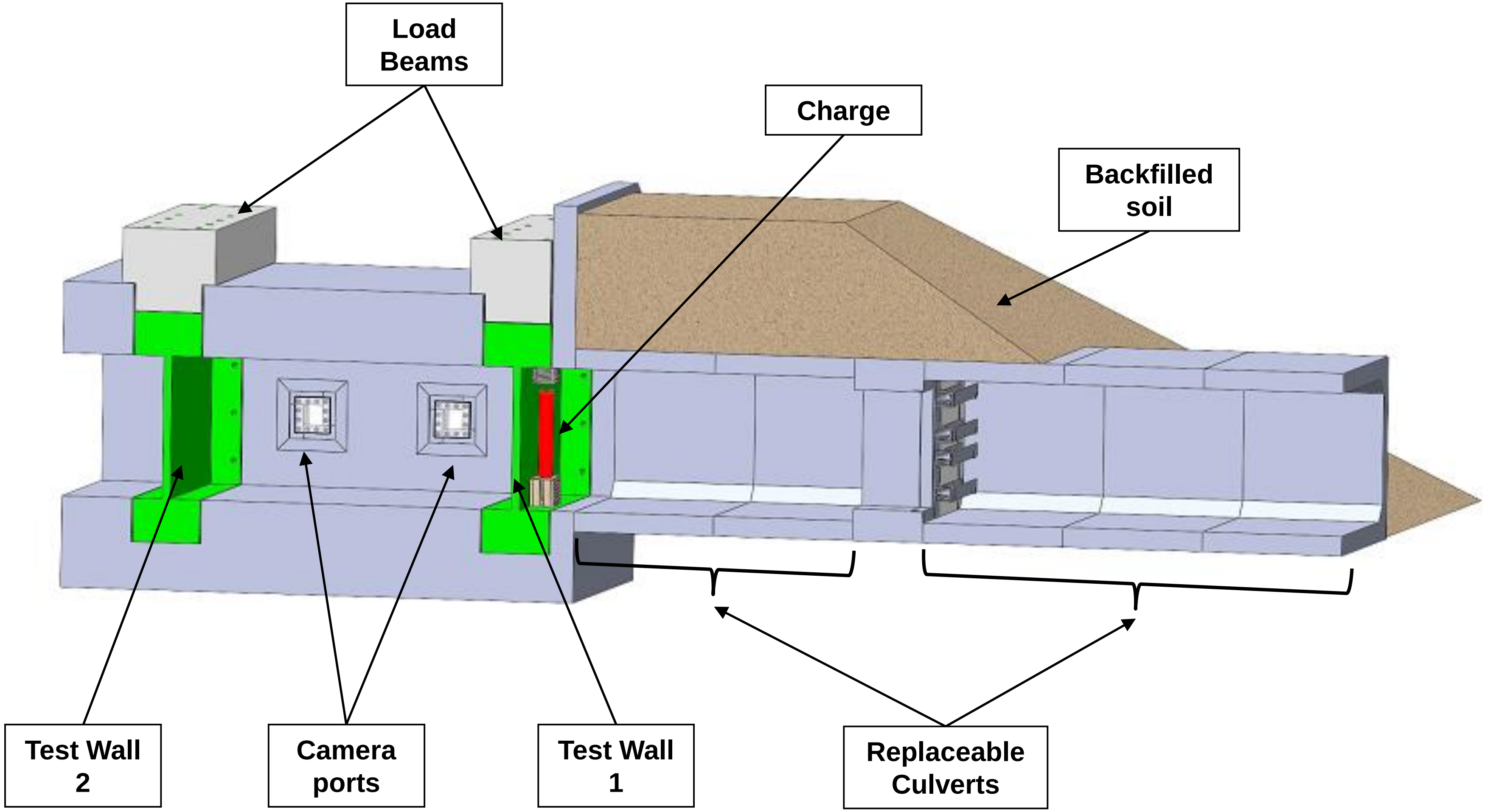
ASICSD: Structural Dynamics Solver specifically for large, plastic deformations

- ❖ Beams, Shells & Solid Elements.
- ❖ Elastic, Plastic, Viscoelastic Materials.
- ❖ Various Concrete Models.
- ❖ Rivets, bolts etc.
- ❖ Erosion Model, but
- ❖ Cracking, rather than erosion for structural break-up
- ❖ Mott's model for weapon case break
- ❖ Johnson and Cook model for thermal softening
- ❖ Non-reflecting BC

CFD/CSD Loose Coupling Approach



Testbed Layout, Elevation View



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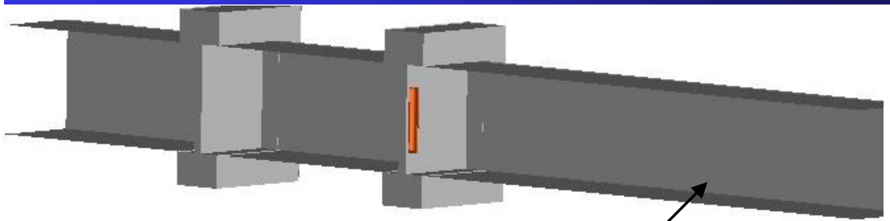
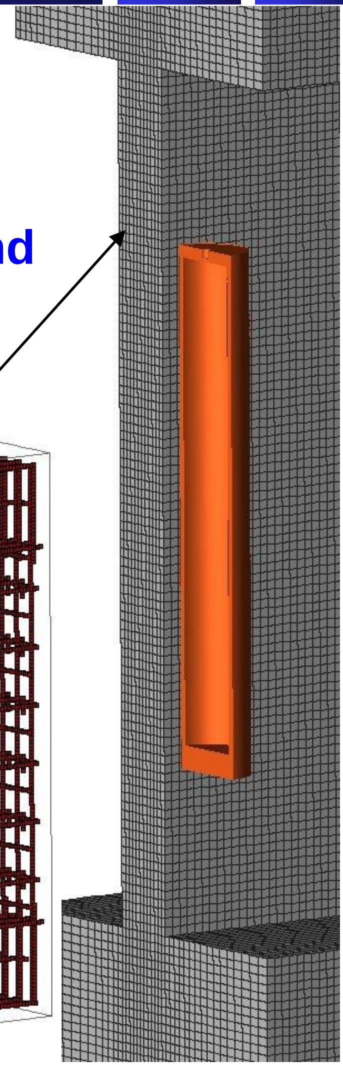
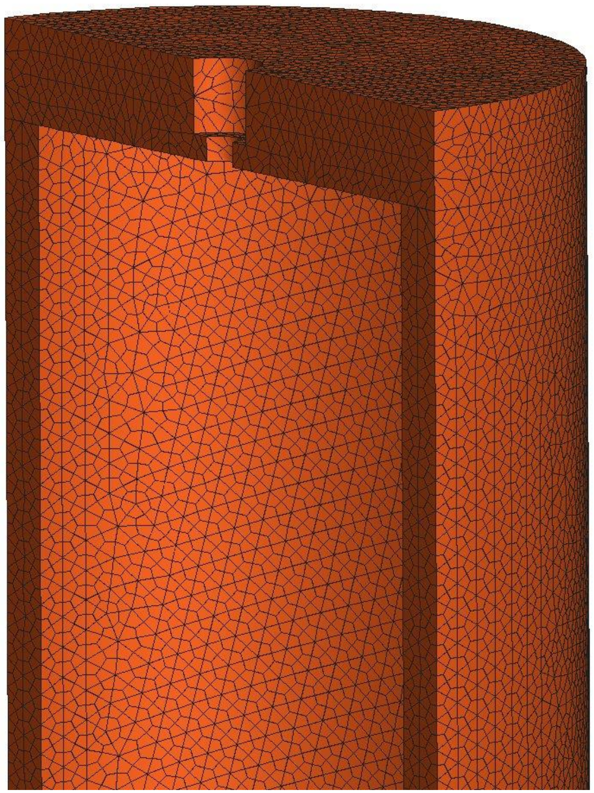
Geometry, materials, mesh (1.3 Melem) and BC

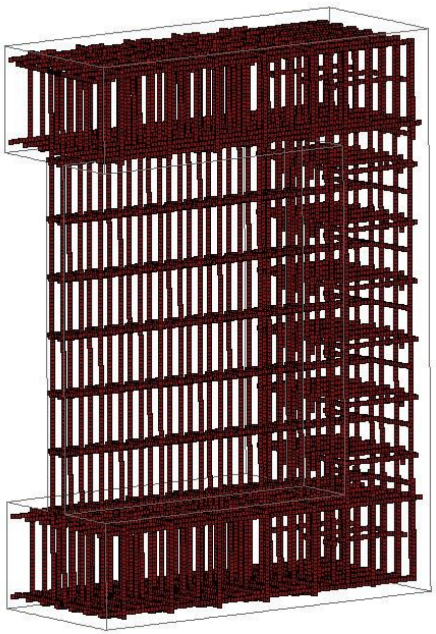


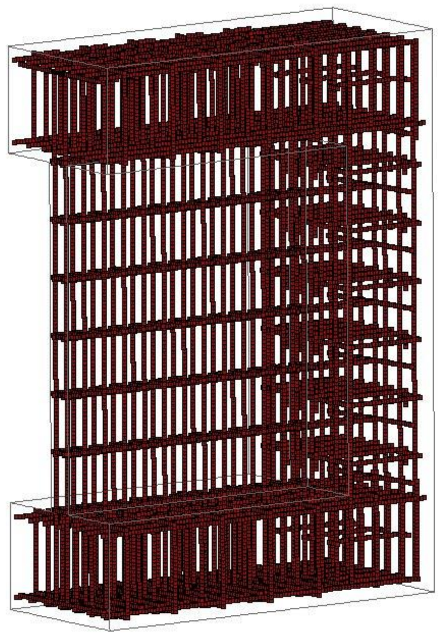
Rigid walls, floor and ceiling.

Symmetric planes.







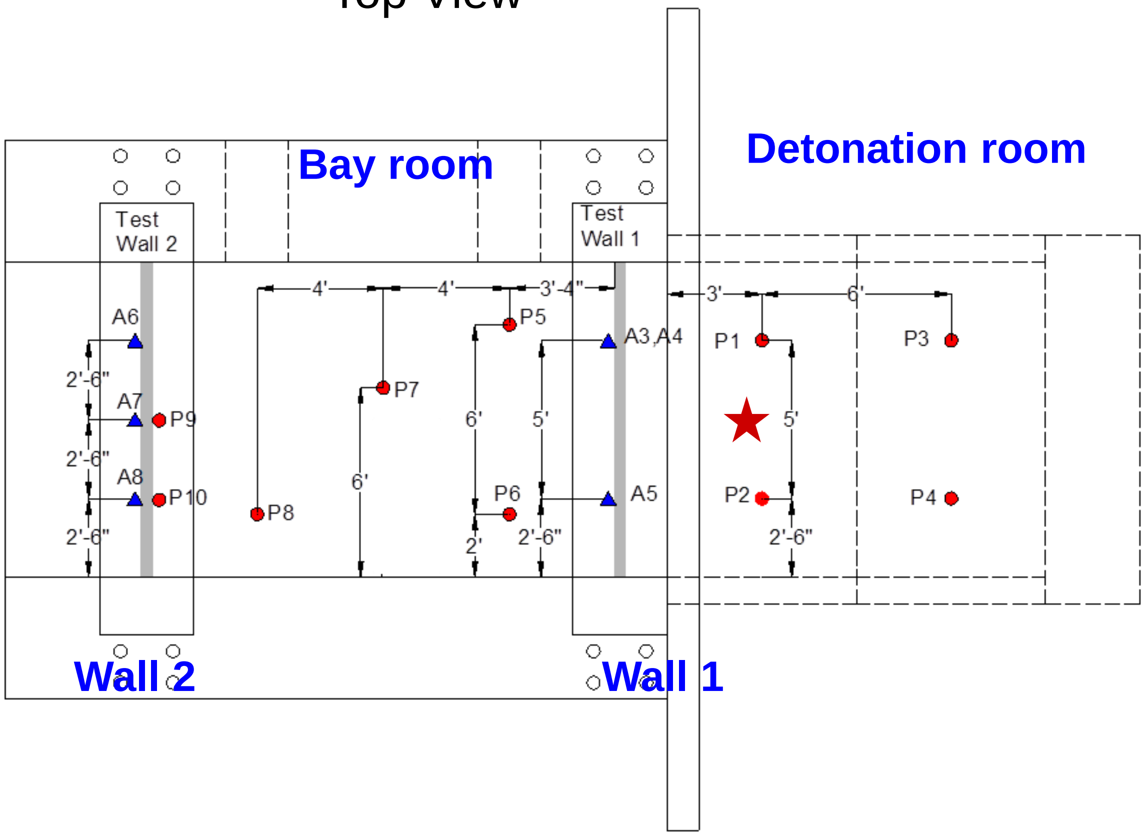


Embedded Rebars

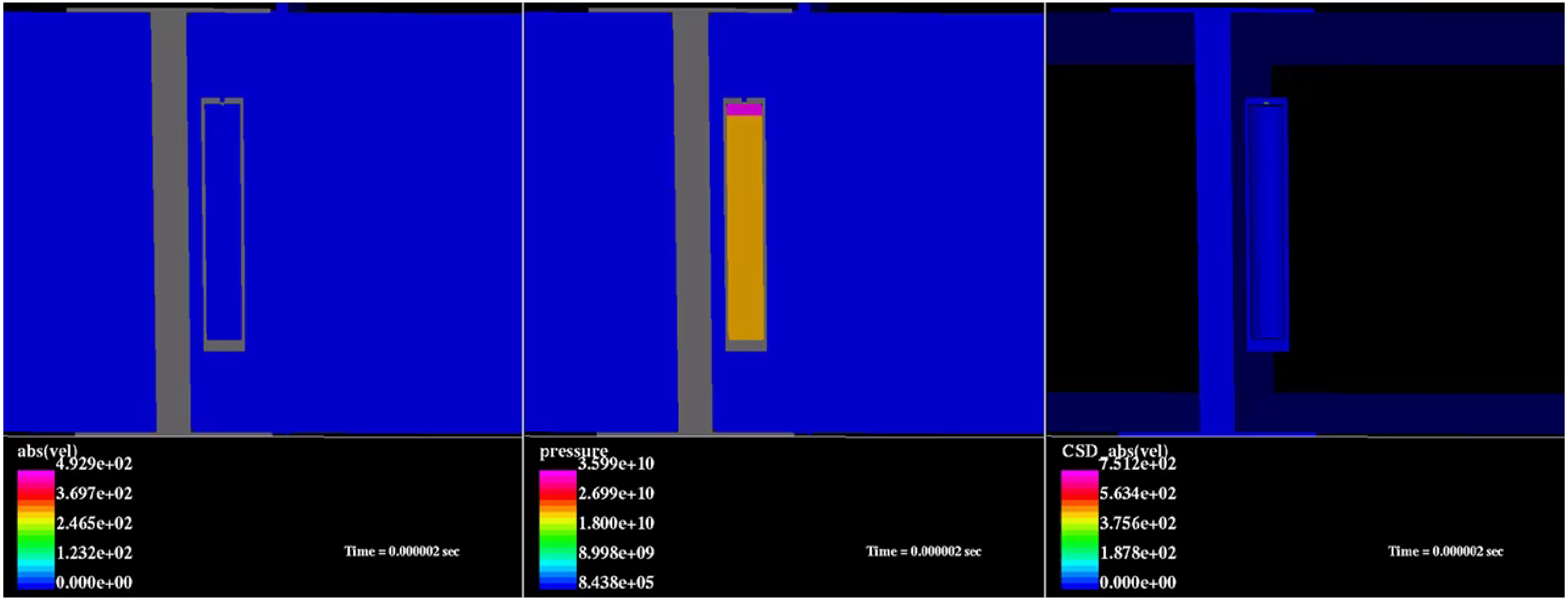
Instrumentation Layout

- **10 pressure gages**
  - **Four in detonation room**
  - **Four in the bay between the walls**
  - **Two on Test Wall 2 on bay side**
- **Six accelerometers**
  - **Three on Test Wall 1**
  - **Three on Test Wall 2**

Top View



Weapon Fragmentation (cgs units)



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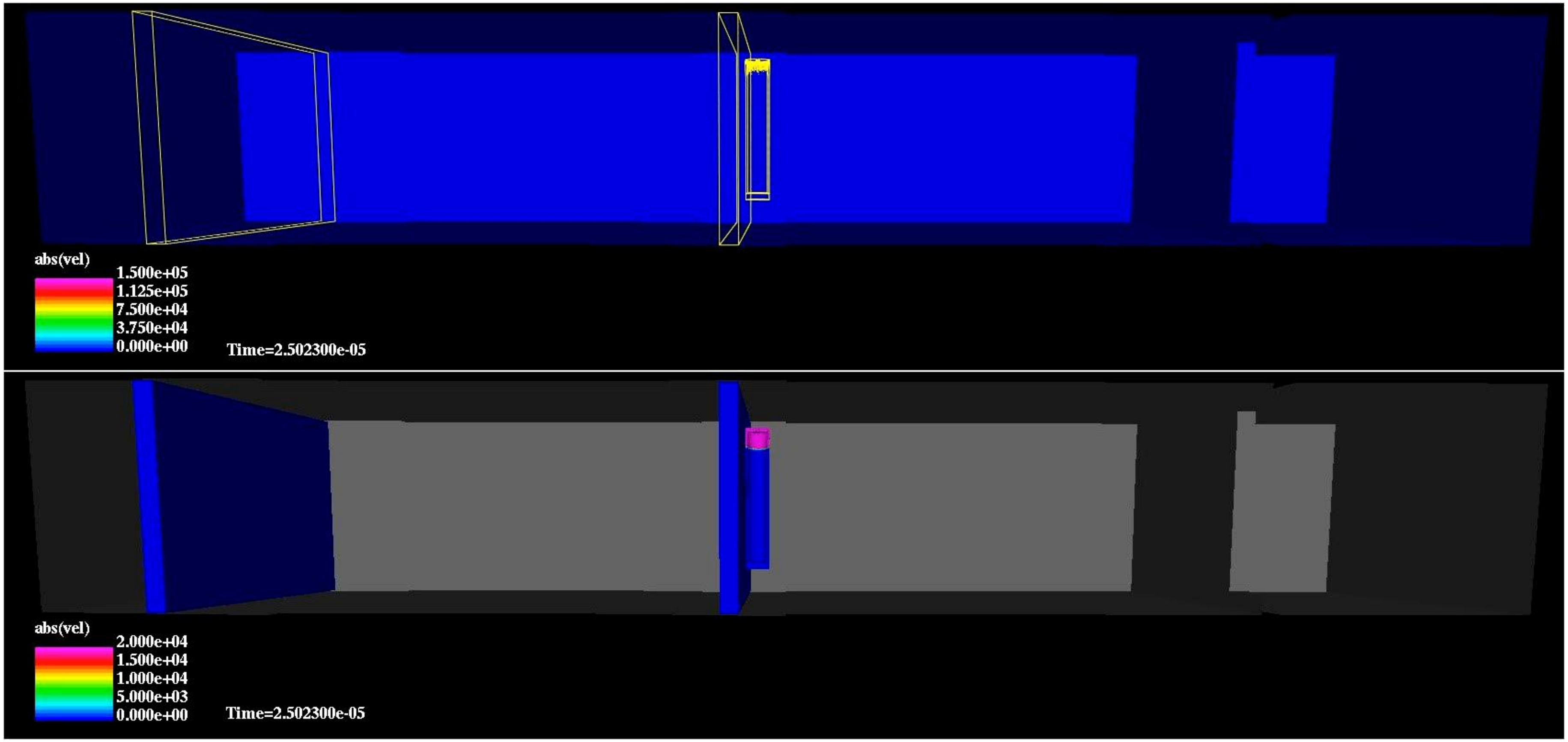
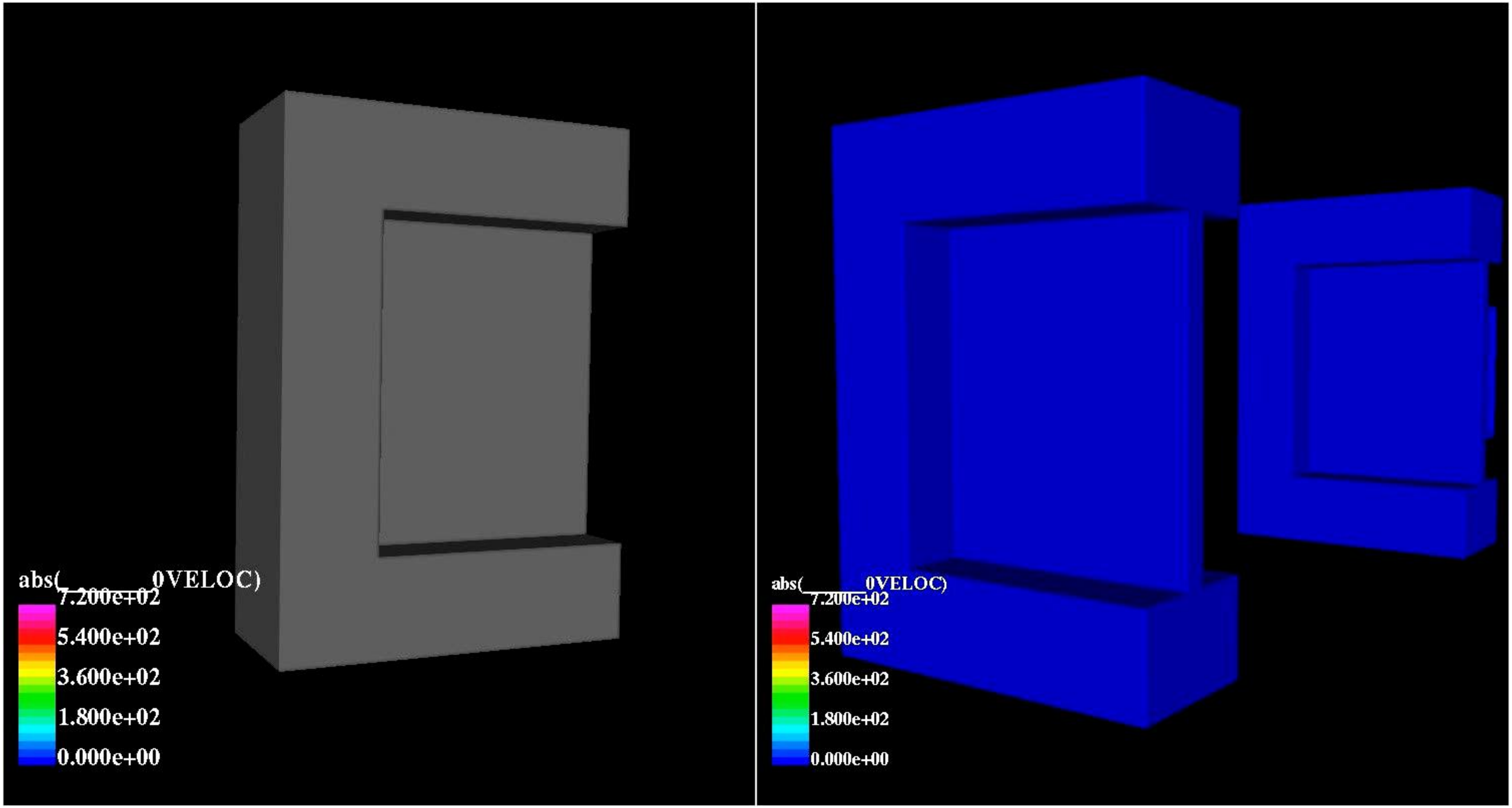
Weapon and Wall Fragmentation (cgs units)

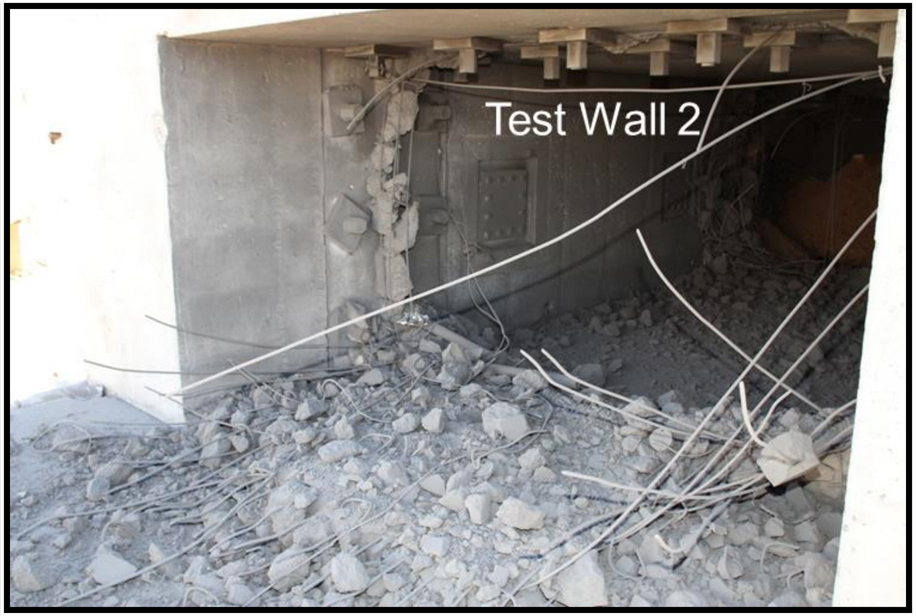


CSD Configuration and Velocities (in/sec)



Post-test views of Damaged Test Walls

Internal view of test wall 1

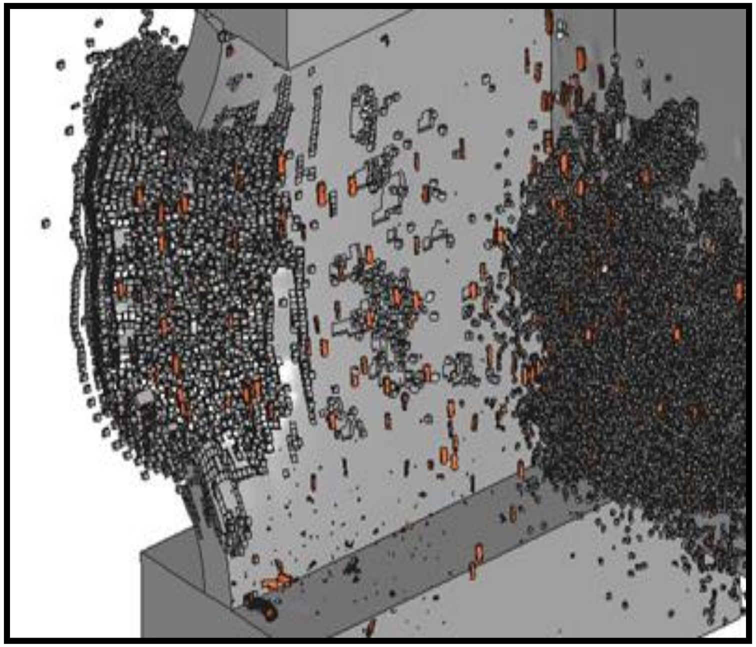


External view of test wall 2

Initial Breach of Wall 1

Test vs. Simulation

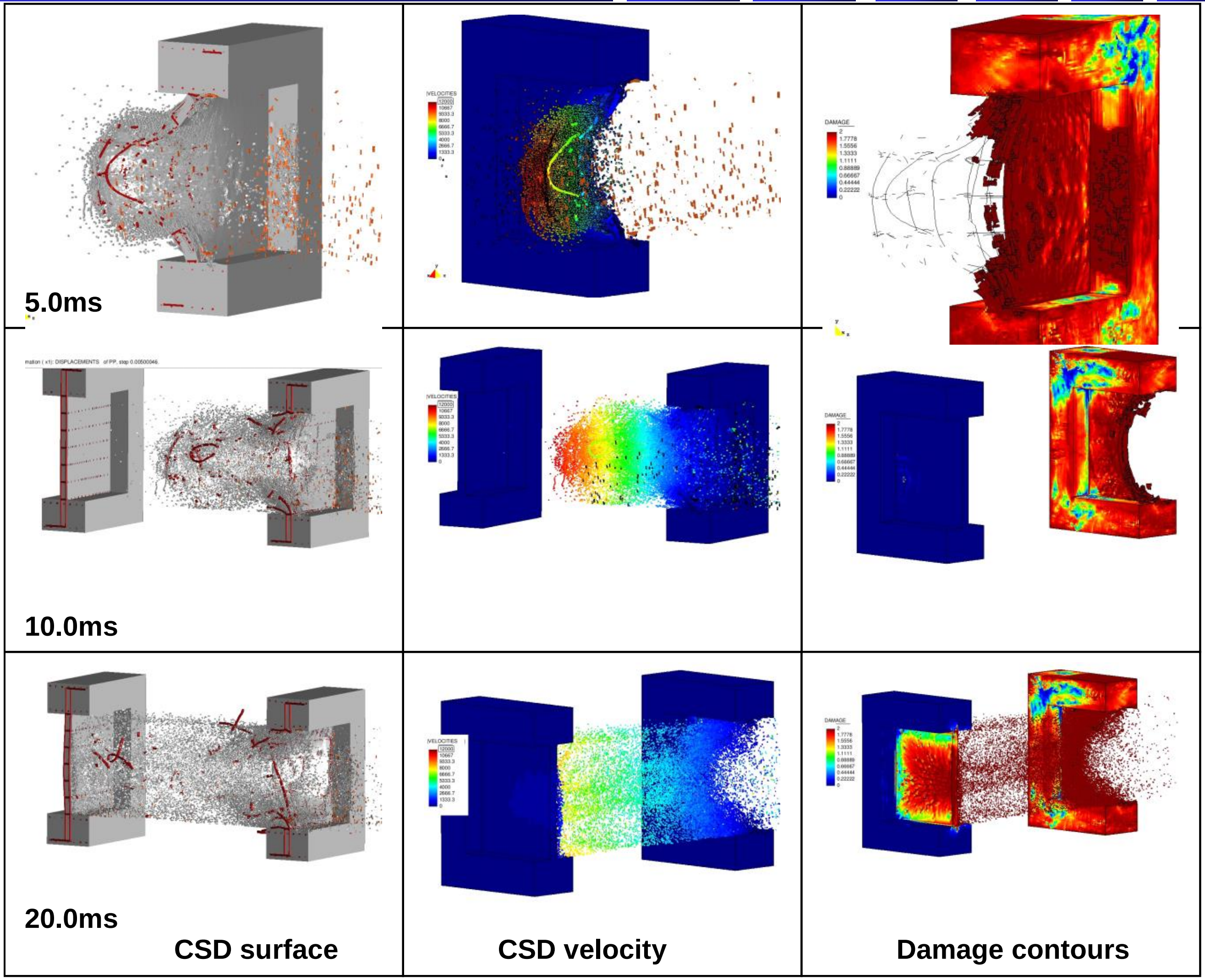
Wall 1 breach: snap from test Video



Wall 1 breach: simulation

Test walls response;

5.0ms, 10.0ms and 20.0ms.



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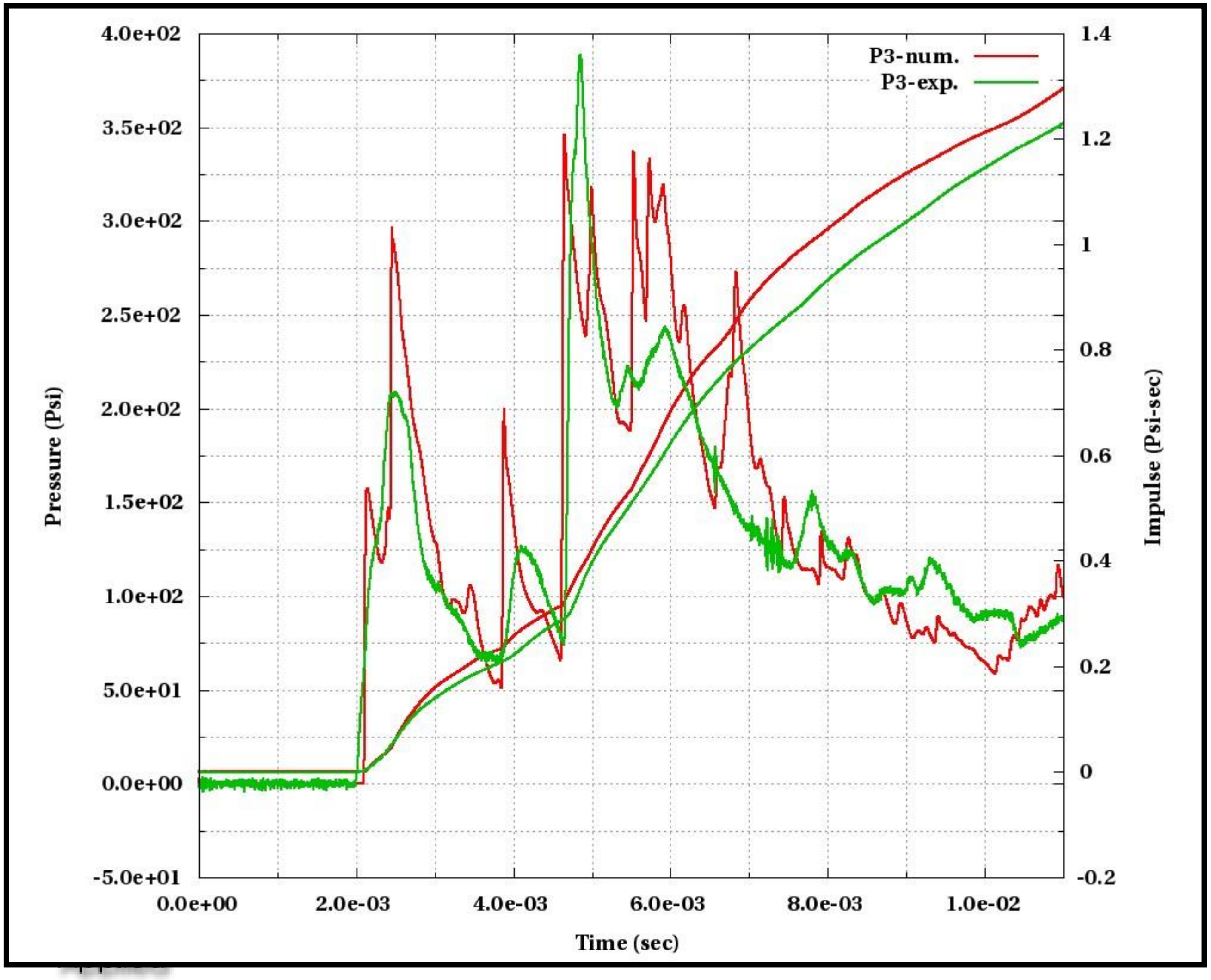
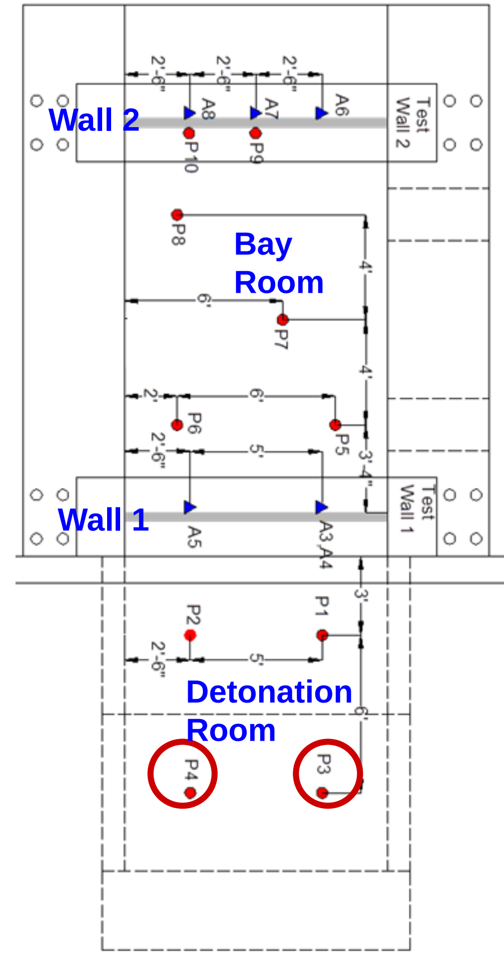
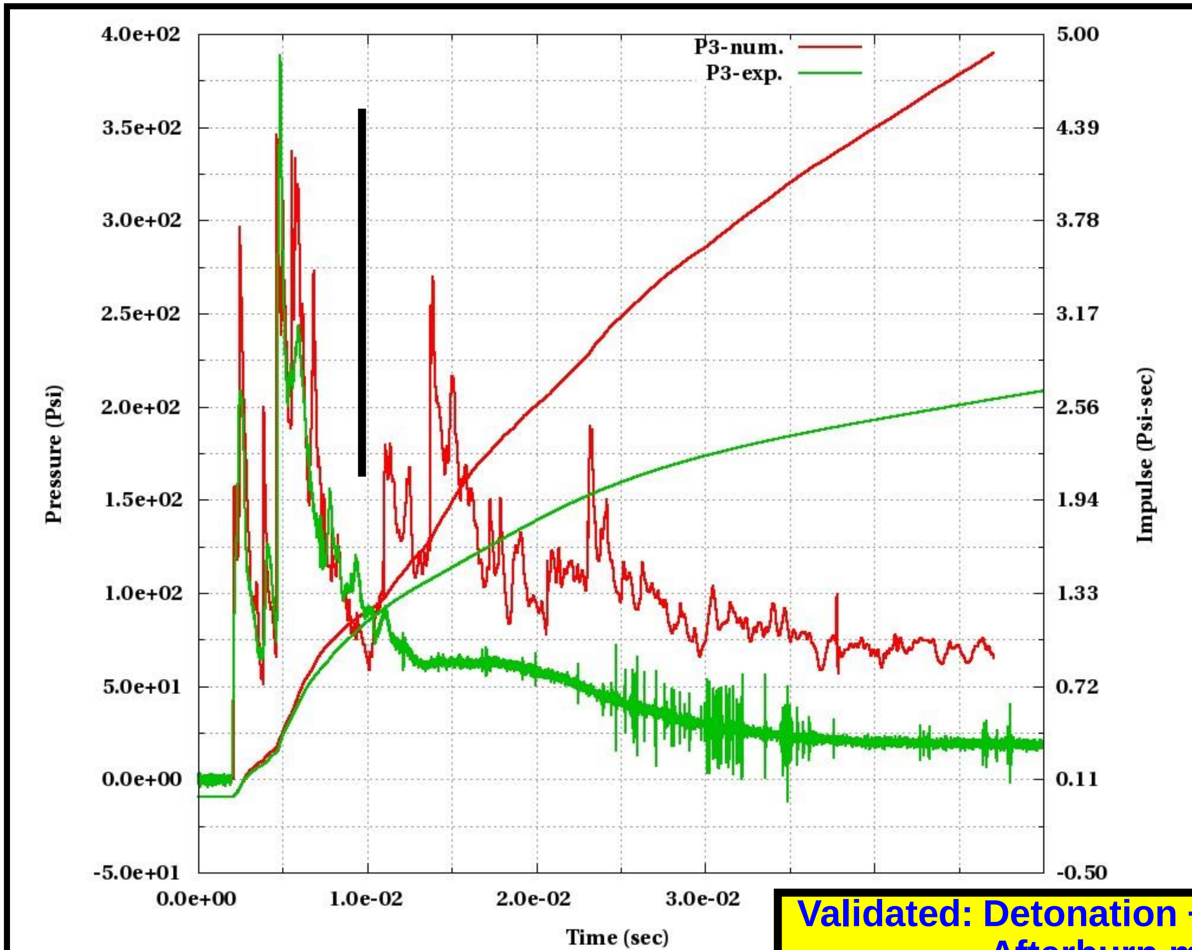
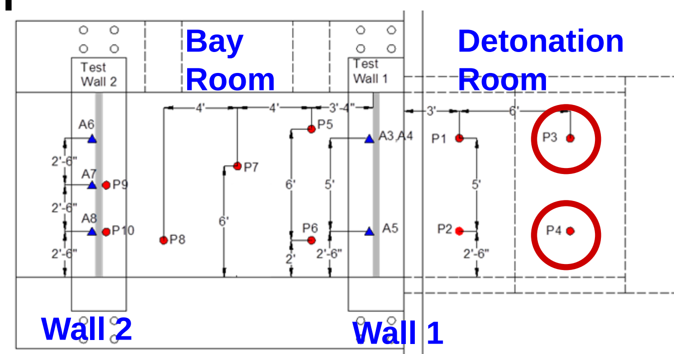
Stations P3-P4: Roof detonation room 10 feet off wall 1 approx. (thru 11 ms)





Stations P3-P4: Roof detonation room 312 cm of wall 1 approx.





Validated: Detonation + combustion for Tritonal.
Afterburn modeling and chemistry
Case fragmentation
Charge and case modeling

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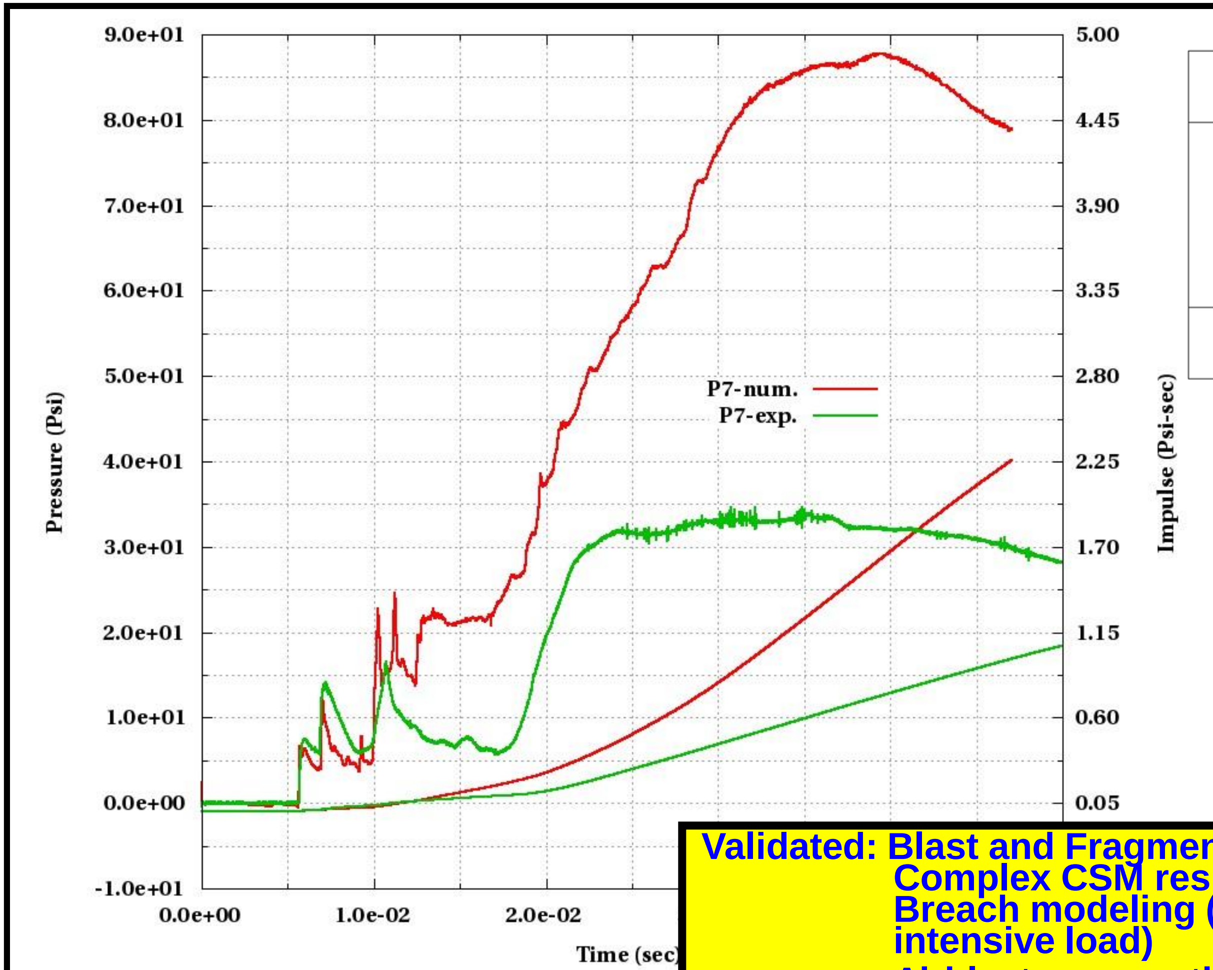
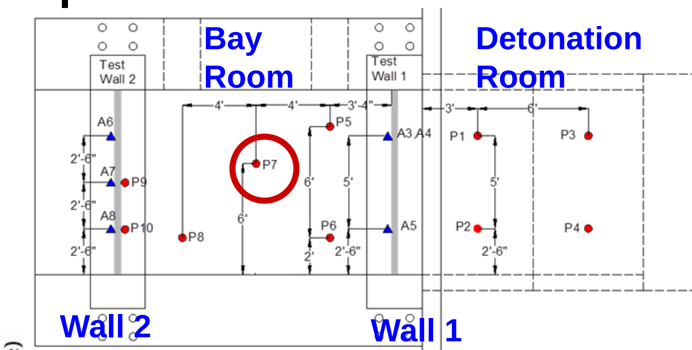
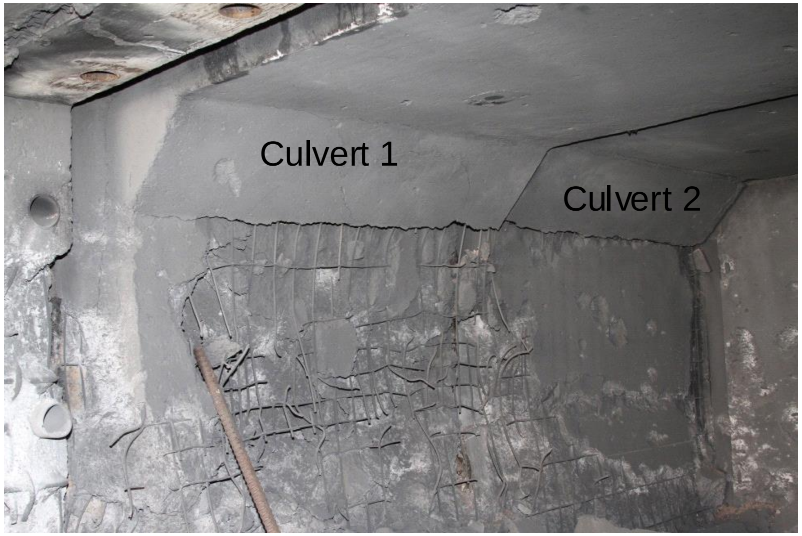
Stations P7: Roof test room 223 cm of wall 1 approx.



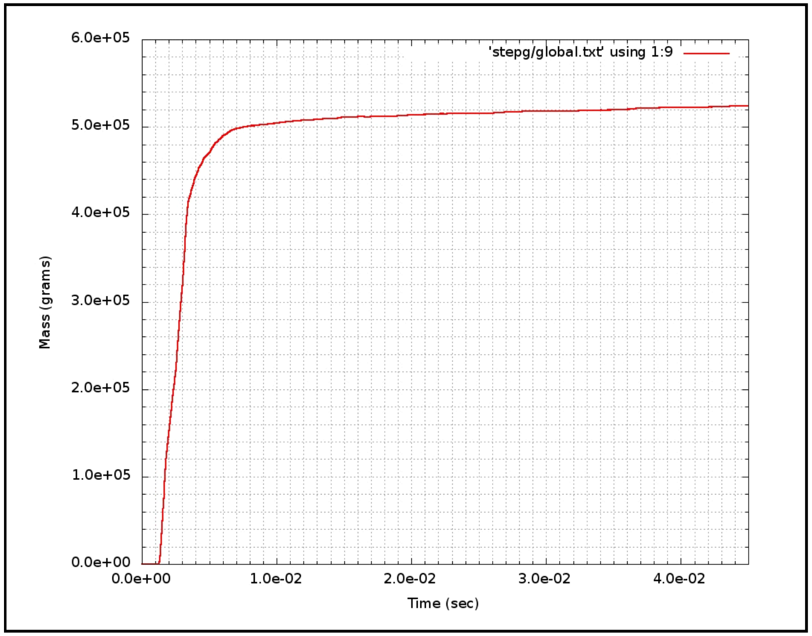


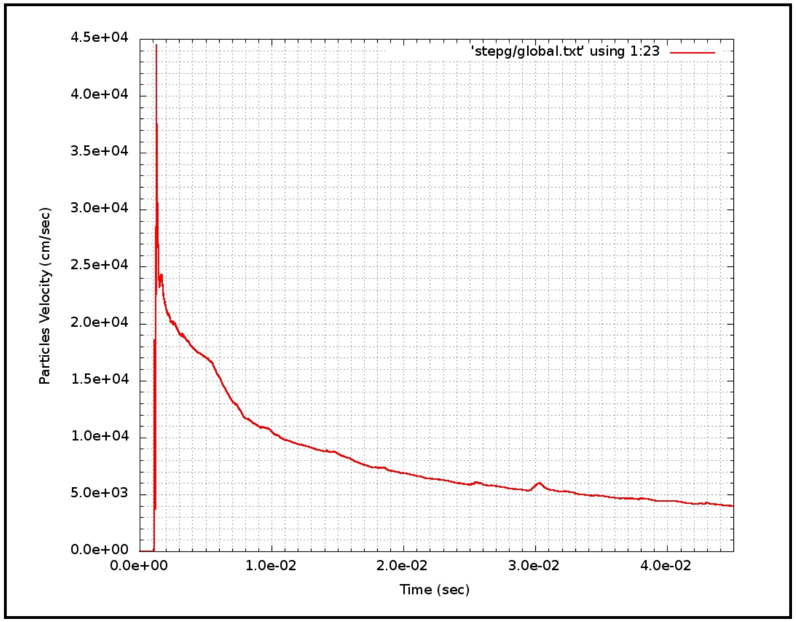
Validated: Blast and Fragment loading on wall 1
Complex CSM response (concrete, rebars, etc)
Breach modeling (wall response to intensive load)
Airblast propagation through damaged surfaces

Test results show the significantly damaged east and west culverts

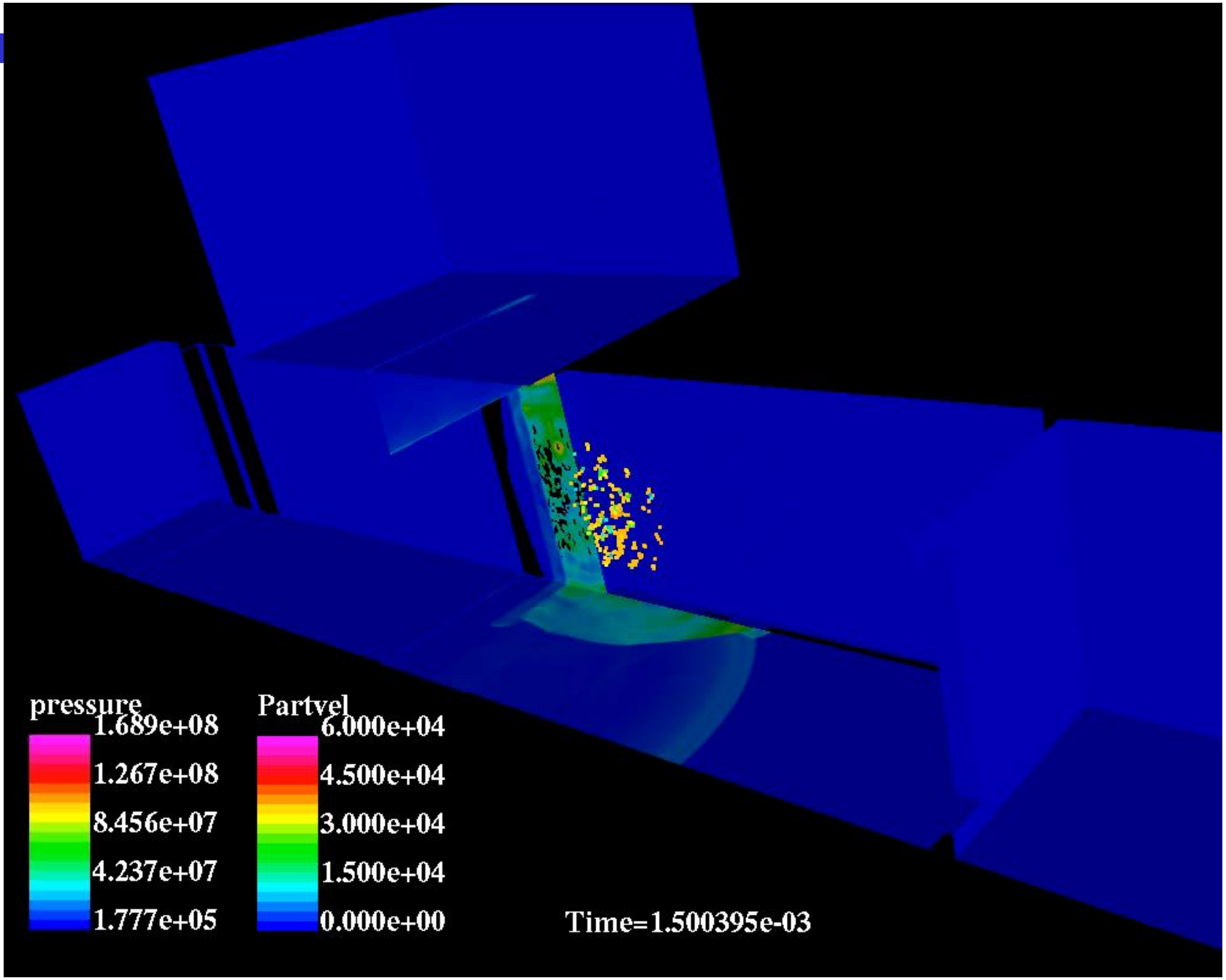


Temporal evolution of dust mass injection and dust velocity off the culvert walls

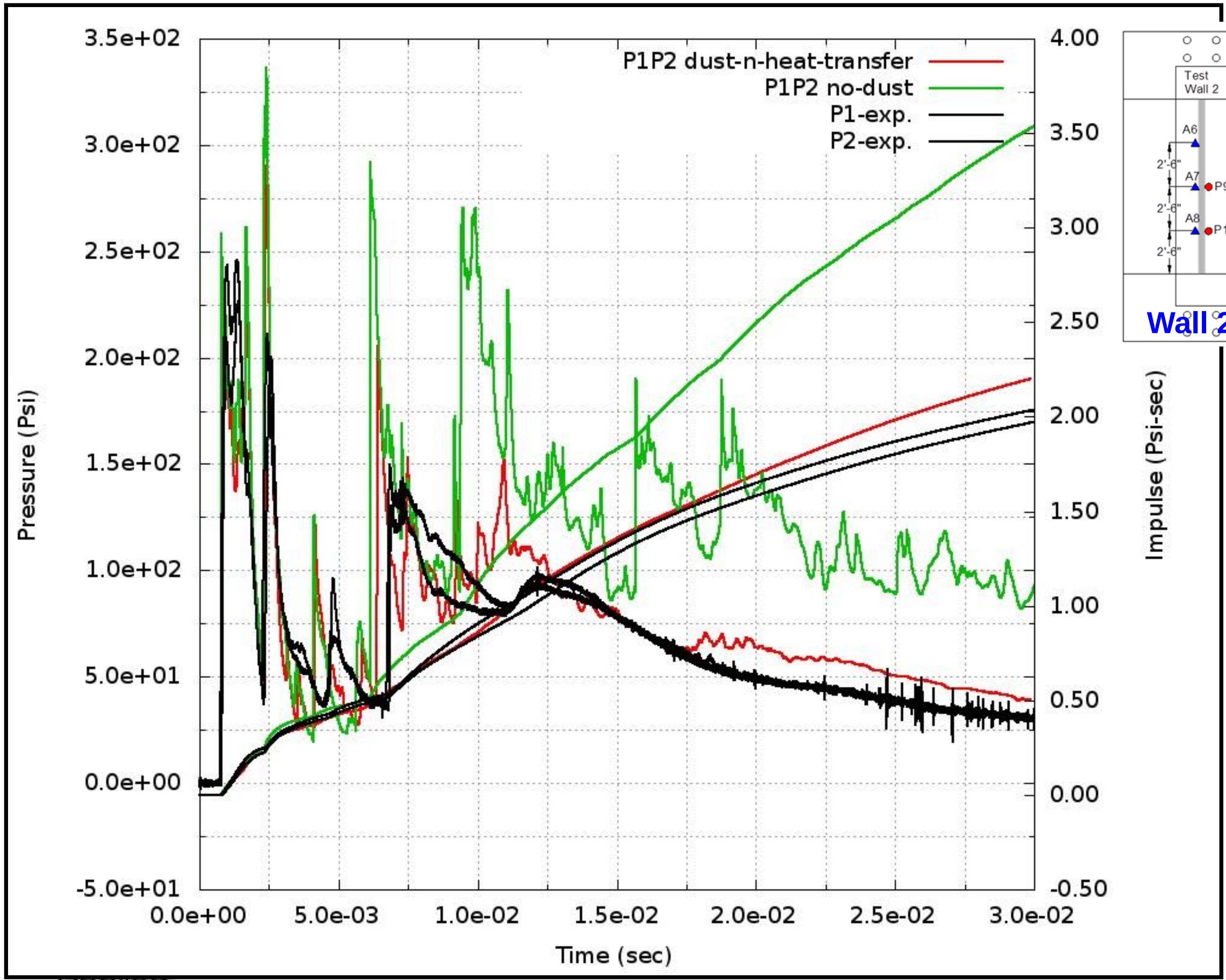


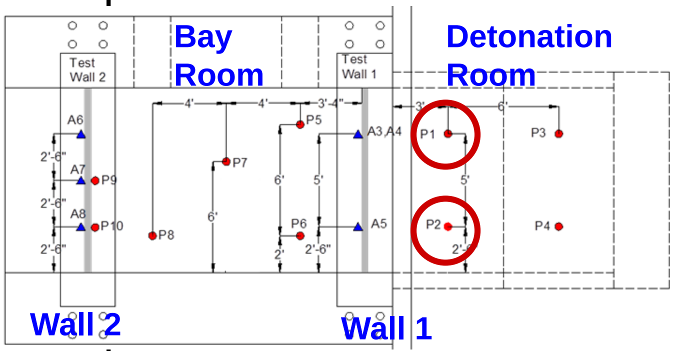


Flow Pressures and Dust Velocities (Animation)

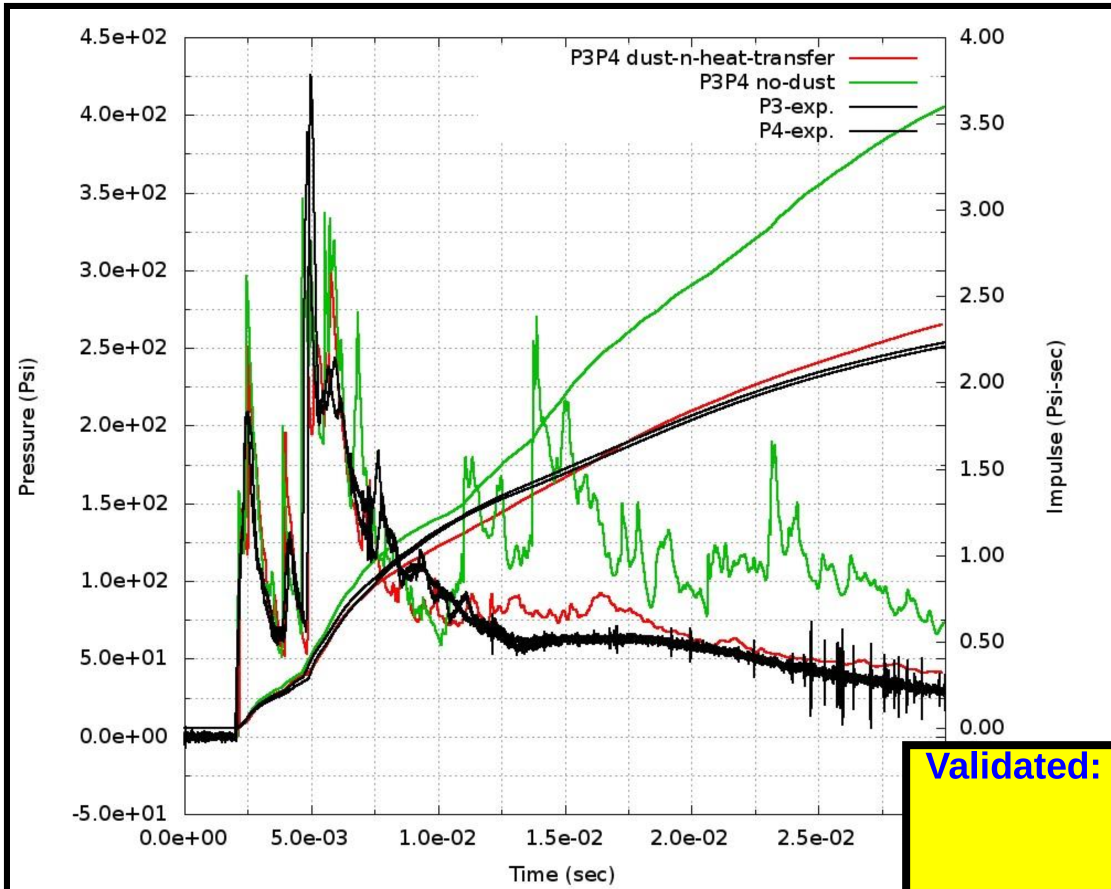


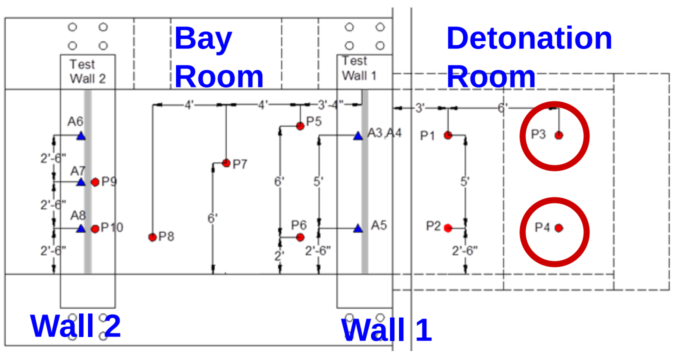
Stations P1-P2: Roof detonation room 4 feet off wall 1 approx. (thru 30 ms)





Stations P3-P4: Roof detonation room 312 cm of wall 1 approx.





Validated: Culvert response to fragment loading (correct dust mass ejection)
- Dust velocity ejection from wall
- Dust entrainment into core flow
- Particle drag and thermal exchange with flow
- Long term accurate energy modeling of gains (combustion) and losses (particles)

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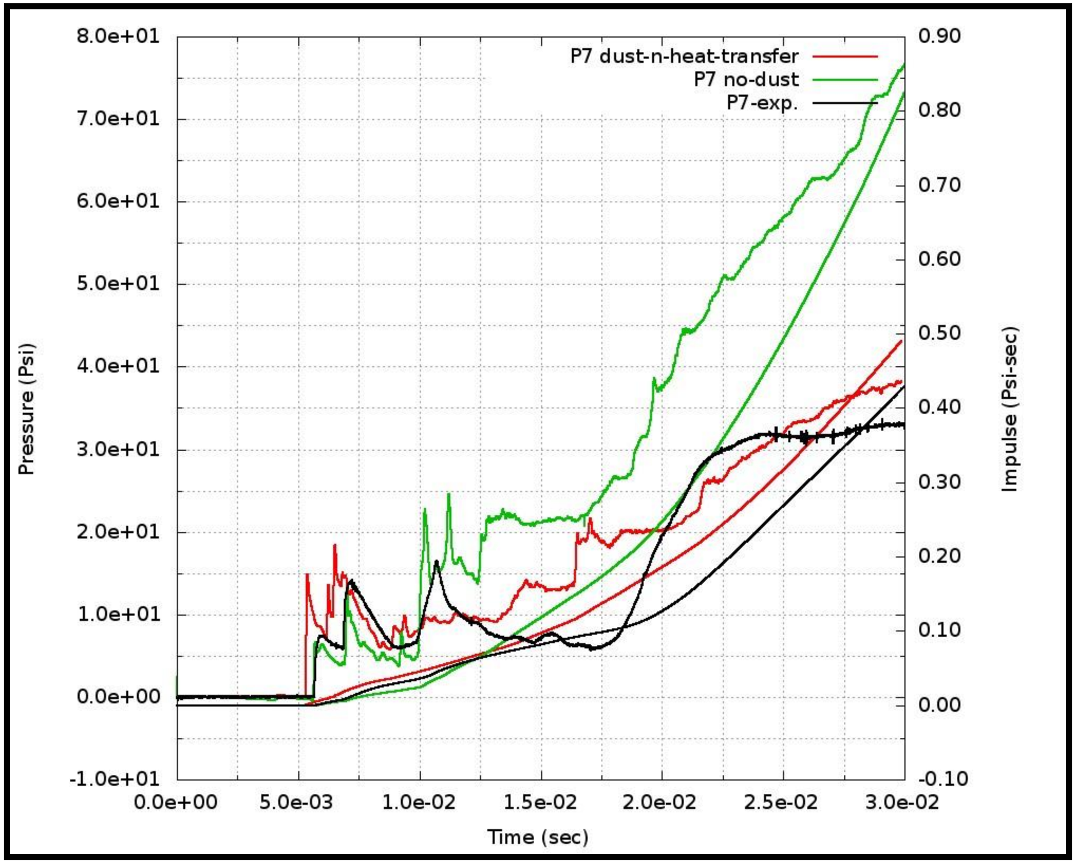
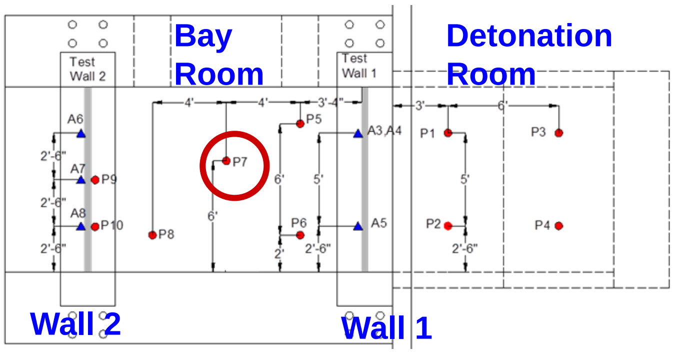
Stations P7: Roof test room 223 cm of wall 1 approx.





Validated: long term combustion + turbulence
Breach modeling
Dust modeling: Kinematic, thermal

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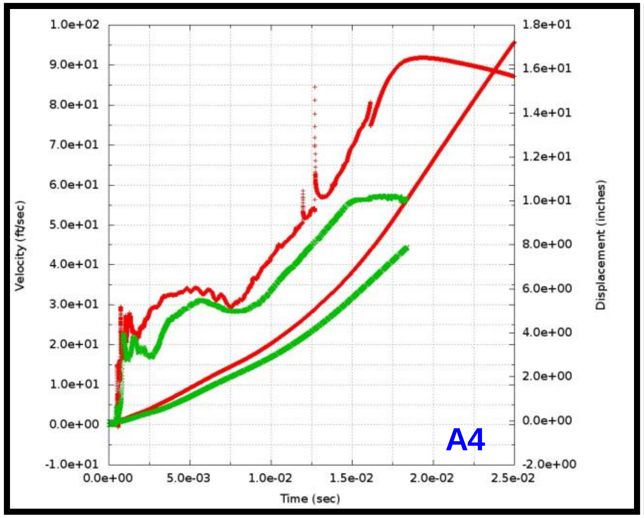
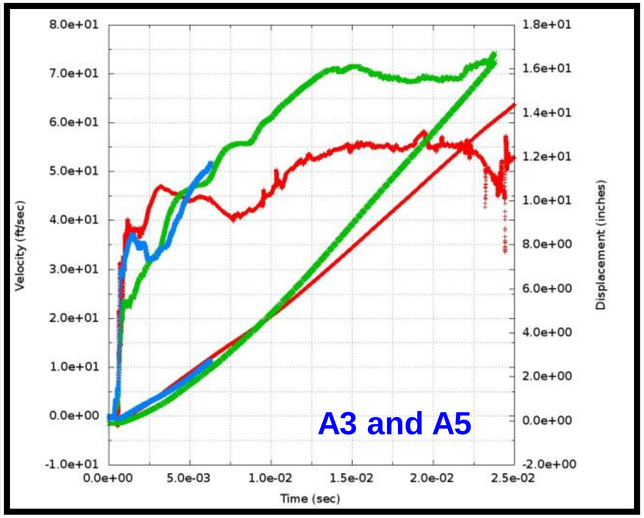
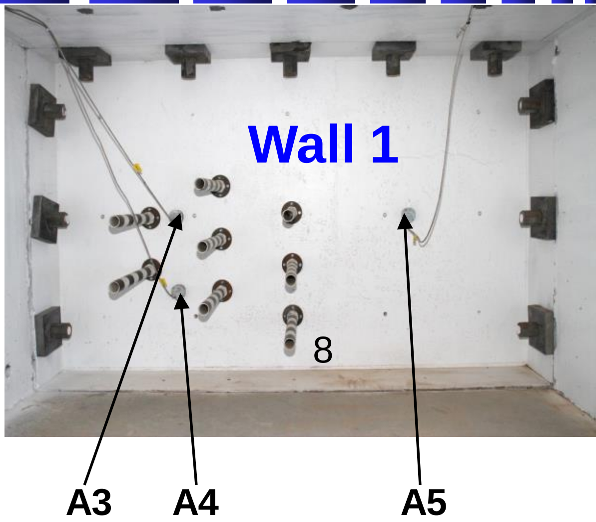
Comparison of Measured and Predicted walls response

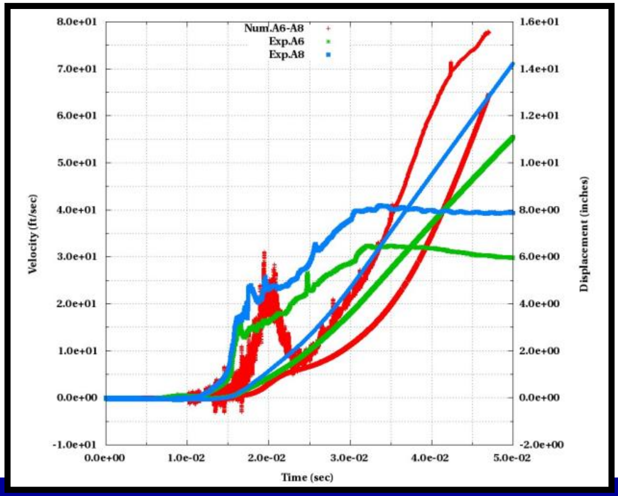


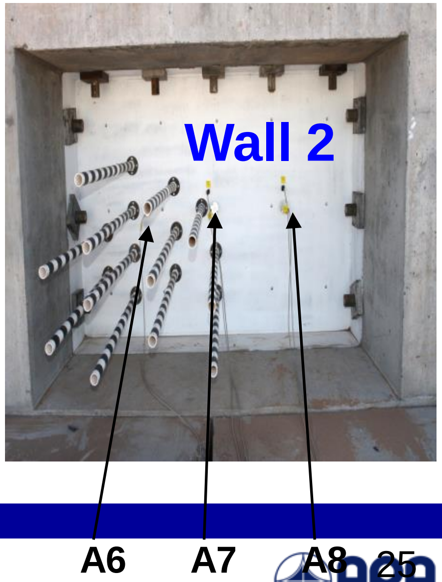




Validated: Blast and fragment loading
Wall response to loading
Breach modeling (short term)
Wall failure in bending (long term)

In summary: both load and response models are accurate





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Final Comments

- FEMAP modeled the detonation and fragmentation of a cylindrical charge and the response of RC test walls to blast and fragment loading.
- Pressure time histories at gage positions agreed very well with the recorded values at the early times (until 10 ms). Afterwards, the simulation results, which at that run did not model culvert damage and dust production, did not agree with the data.
- Post-test evidence indicates that a large volume of concrete dust was generated by fragment impact on the culvert. This phenomenon was not included in the initial analysis that treated the culvert as rigid.
- The culver modeling within the coupled CFD/CSD model was changed from rigid to responding. Element failure produced dust particles due to weapon fragment impact. Including drag and heating effects on these dust particles in the simulation produced waveforms and pressure time histories that agreed well with the experimental data, both within the detonation room and the Bay room.
- Test walls failure modeling matched the recorded test videos
- The early wall 1 failure resulted from fragment impact, while the later resulted from pressure load.
- The dominant load responsible for wall 2 failure was produced by wall 1 concrete debris, rather than by the blast load.