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Development of Modeling Methodologies for Simulation of Fuze Firesets Embedded in Explosive Fill

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Motivation for New Methodology Development

Recent desire in the DoD to explore the possibility of embedding fuze firesets within the explosive fill of hard-target penetrating weapons

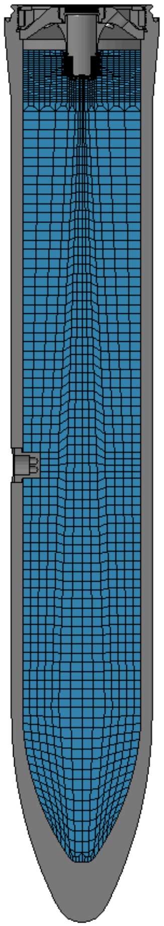
- Likely to enhance fuze survivability by providing a “softer” ride

Scenario creates a new set of design challenges that need to be addressed during fuze development

- Explosive fill compression/movement expected to subject fuze to high-pressure and high-acceleration environment

Legacy approach of modeling explosive fill with Lagrange finite element modeling methodologies no longer appropriate for properly capturing embedded fuze-explosive fill interaction

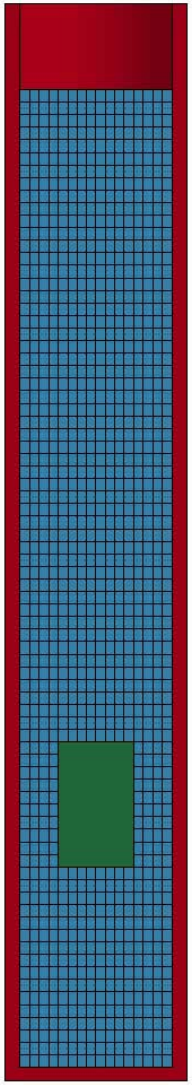
Penetrating Warhead with Lagrange Explosive Fill Model



Lagrange Explosive Fill Model Deficiencies

A number of deficiencies and difficulties associated with modeling systems embedded in Lagrange explosive fill exist

- Explosive fill mesh has a difficult time flowing around and conforming to movement of embedded system
- Extreme local deformation of the explosive fill elements can result in longer simulation runtimes, less accurate results, contact algorithm failure and simulation crashing
- Explosive fill mesh should match exterior geometry of embedded system to ensure no gaps exists
  - Requires explosive fill to be re-meshed for any change in embedded system geometry/location



Arbitrary Lagrange Eulerian Formulation (ALE)

Combines the strengths of Lagrangian and Eulerian modeling techniques

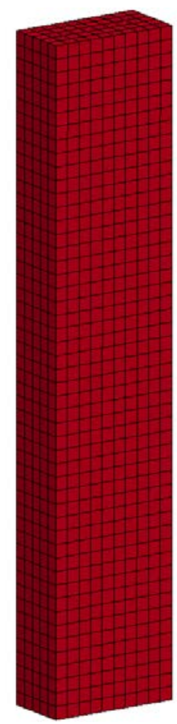
- Allows materials to flow (advect) through stationary mesh like a Eulerian formulation, mesh distortion does not occur
- Transports the stress matrix with the material, capturing stress-strain effects like a Lagrangian formulation
- Interaction of ALE material with other Lagrange parts possible in LS-DYNA

Captures desired physics for modeling systems embedded in explosive fill

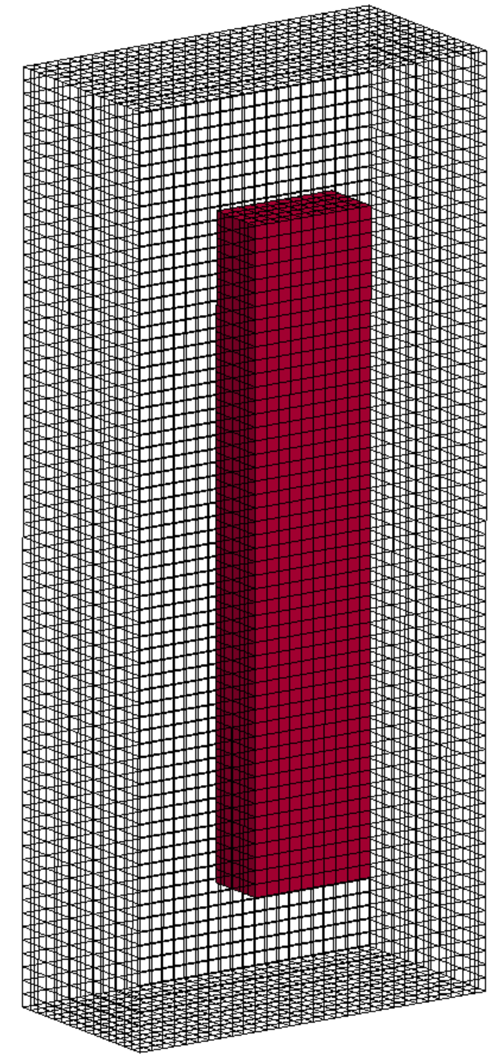
LS-DYNA includes algorithm to perform an auto-fill of explosive fill around embedded system

- No need to create a new mesh for change in embedded system geometry/location

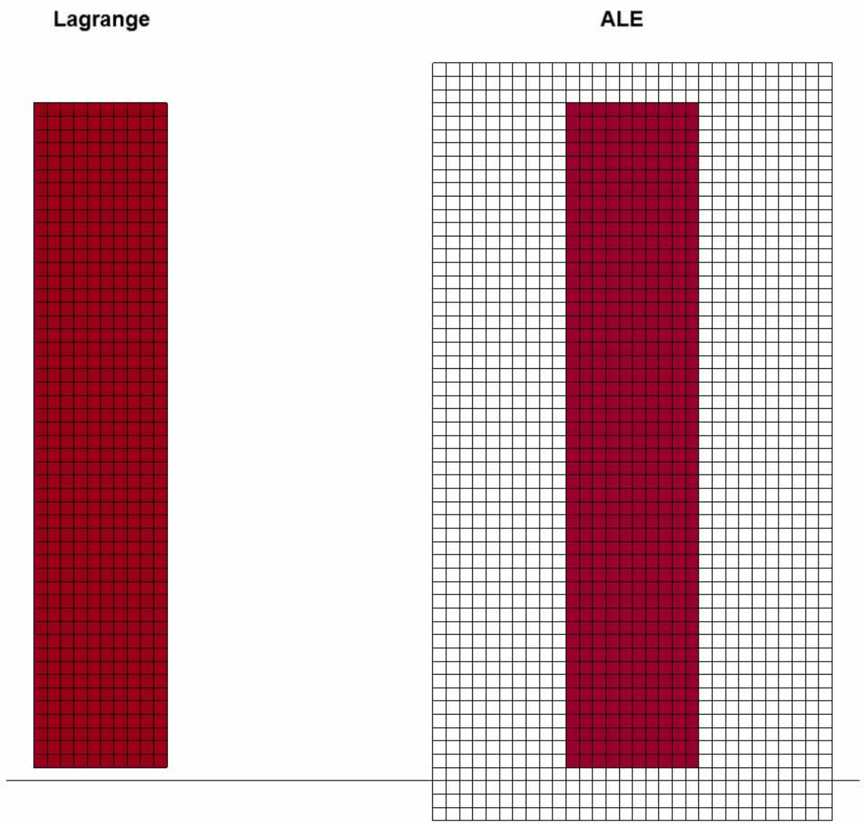
Lagrange Formulation



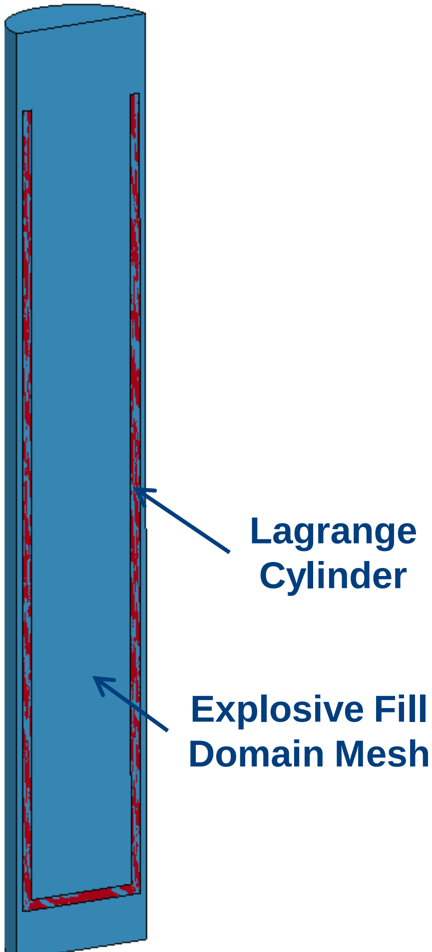
ALE Formulation



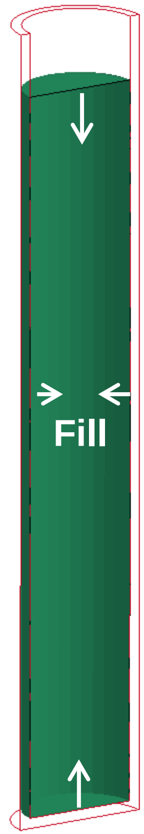
Lagrange versus ALE – Taylor Anvil Problem



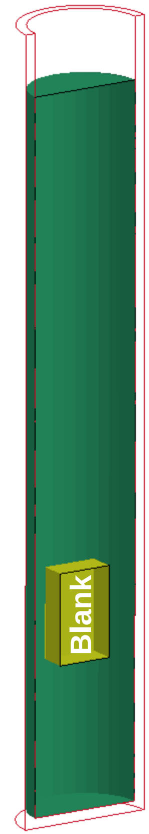
Method for Creating ALE Explosive Domain



Step 1: Create fill domain mesh encompassing possible extents of fill



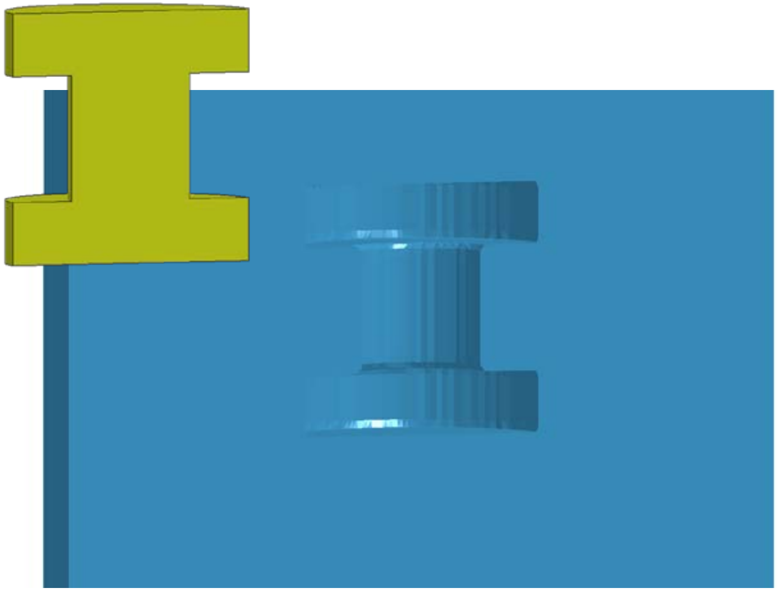
Step 2: Using faceset defining explosive geometry and extents “fill” with explosive

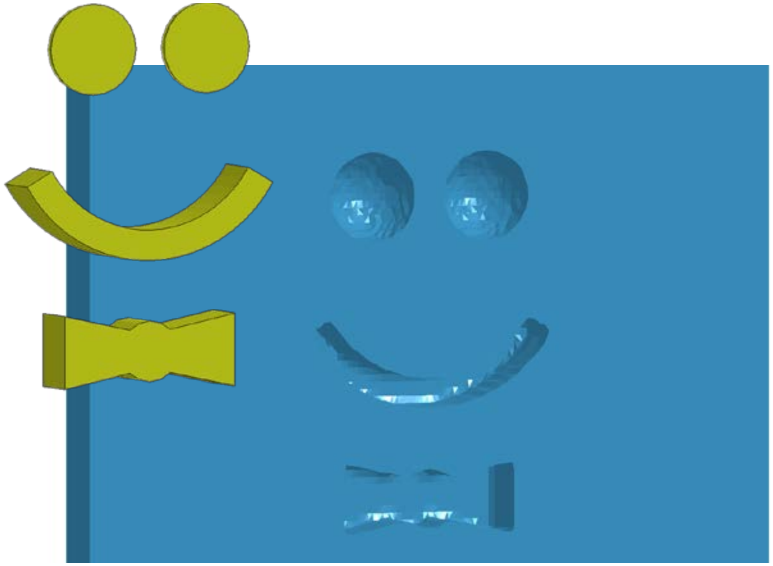


Step 3: Using faceset defining embedded system geometry extents “blank” explosive

Resulting ALE Explosive Fill (PrePost visualization errors common at sharp corners)

Demonstration of Various Embedded Geometries





Comparative Study

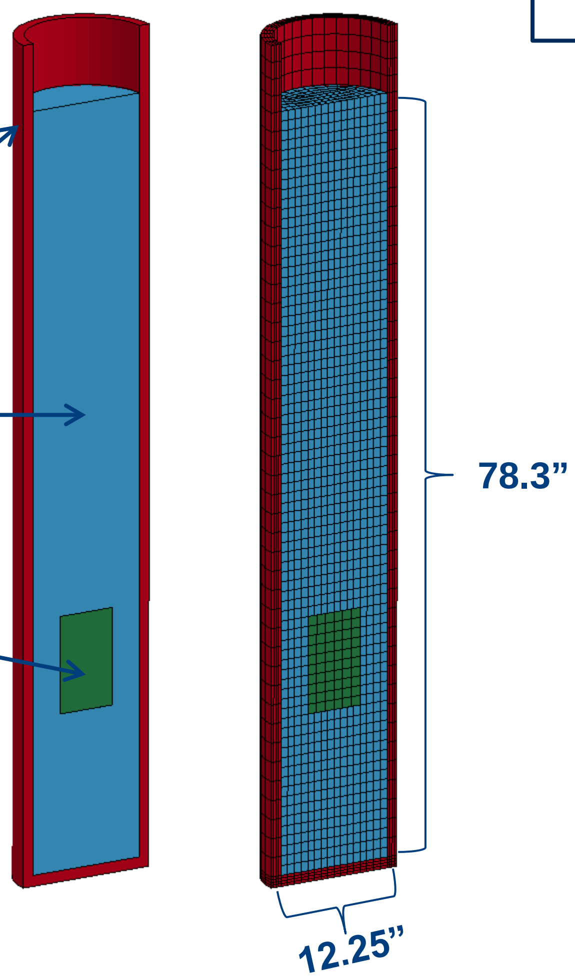
Embedded Lagrange System Geometry

Lagrange Explosive Fill

Cylinder (4340 Steel)

Lagrange Explosive Fill (AFX-757)

Lagrange Embedded System (4340 Steel with AFX-757 Density)

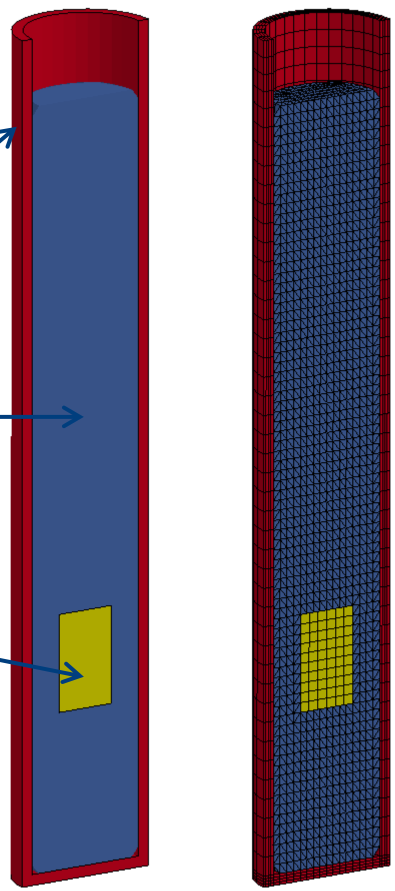


ALE Explosive Fill

Cylinder (4340 Steel)

ALE Explosive Fill (AFX-757)

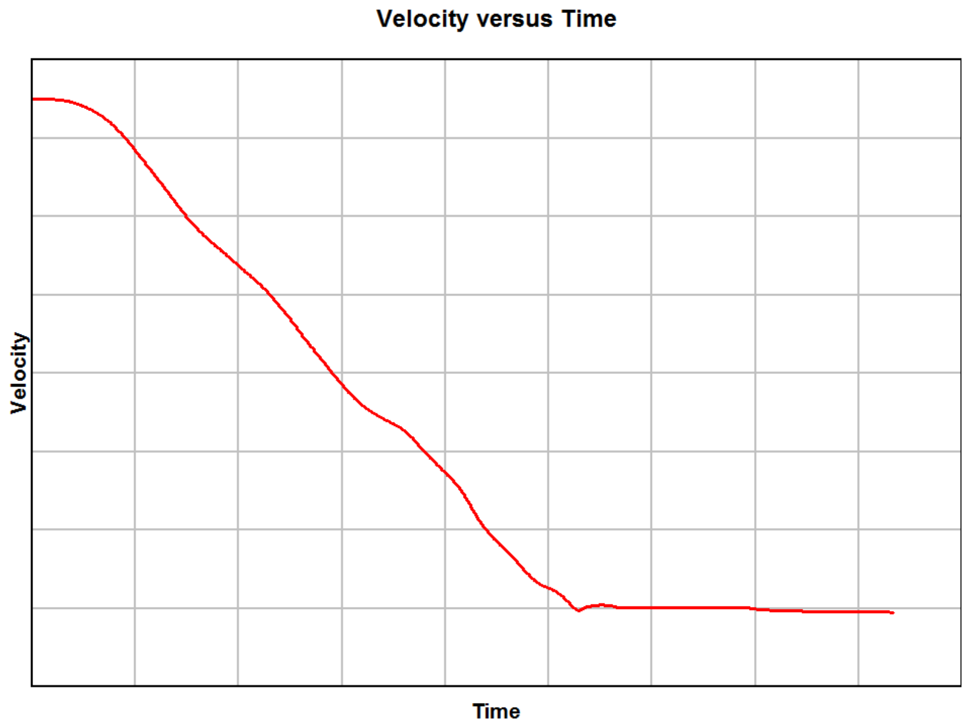
Lagrange Embedded System (4340 Steel with AFX-757 Density)



Concrete Penetration Velocity Trace

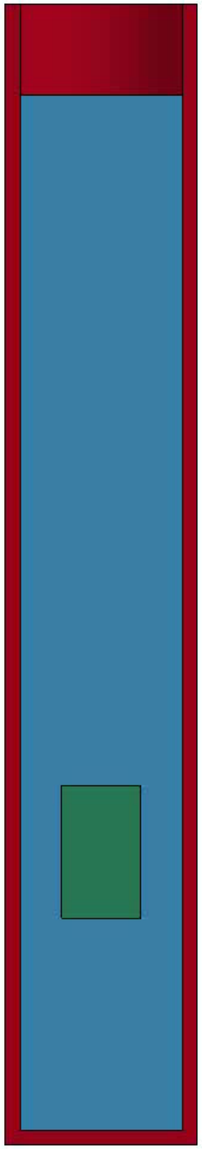
Velocity trace from simulation of penetrator interacting with monolithic concrete target used to drive exterior of test articles

- Long duration-high G-loading environment results in compression of explosive fill
- Cylinder is constrained only in axial direction
- No velocity profile in radial direction
- Case is allowed to flex radially due to internal pressure from compressing explosive fill

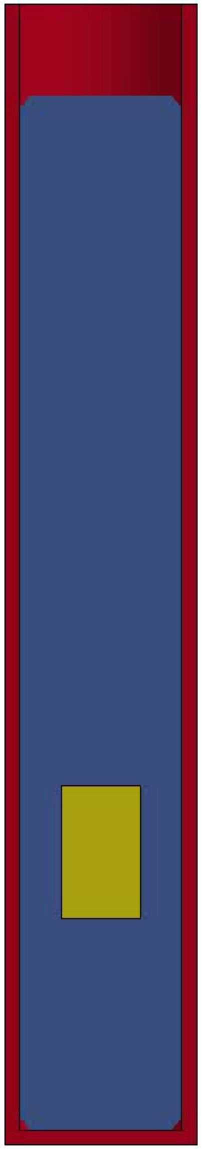


Results

Lagrange Fill



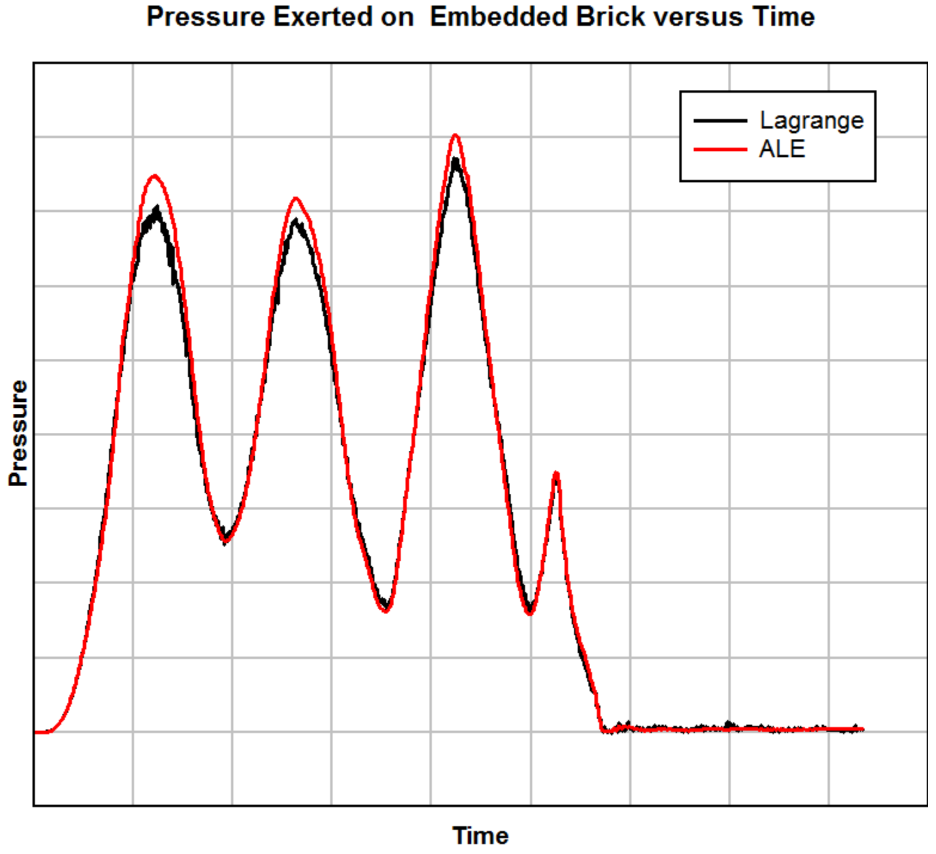
ALE Fill



Results – Explosive Fill Pressure on Embedded System

Pressure loading of explosive fill on embedded block recorded during simulation for both systems

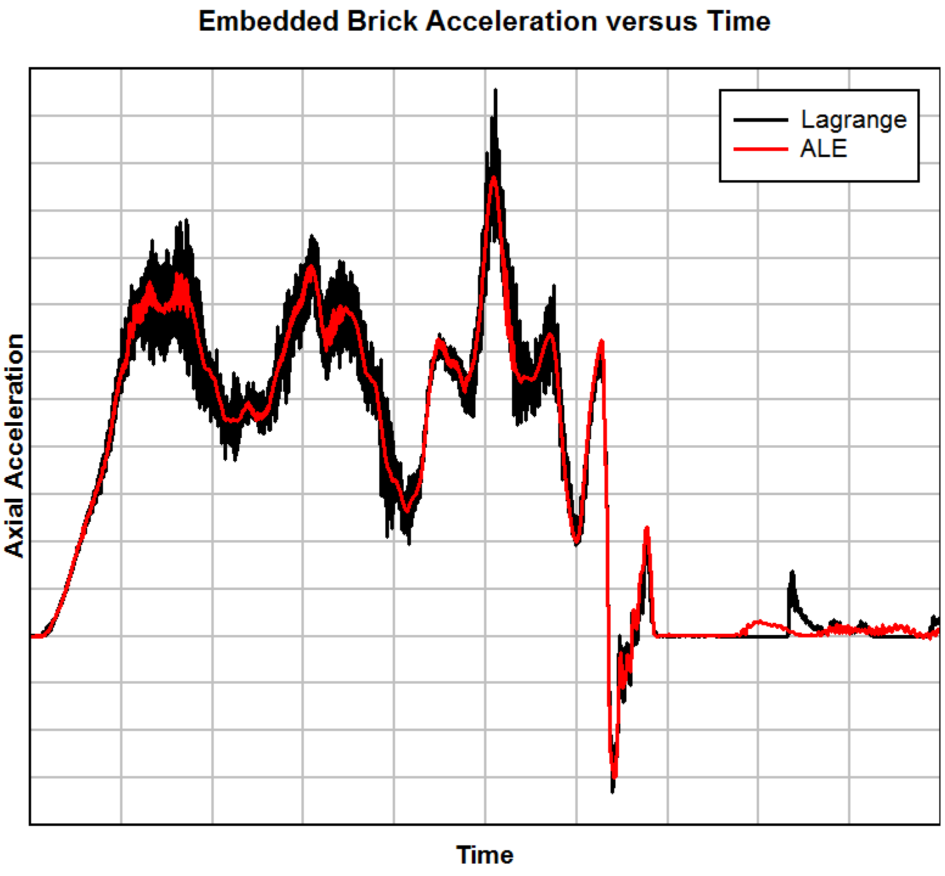
- Consistent pressure levels and durations experienced by embedded block in both Lagrange and ALE simulations
- ALE pressures has slightly higher peaks as Eulerian mesh is able to remain in contact with entire exterior of embedded brick during penetration event – better captures "flow" of explosive fill
  - Improvement over Lagrange formulation



Results – Embedded System Axial Acceleration

Axial acceleration of embedded block recorded during simulation for both systems

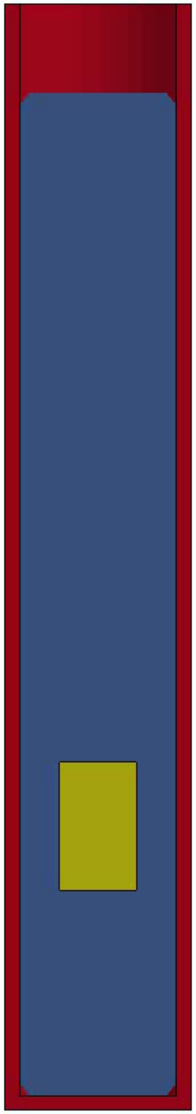
- Consistent trends seen for axial acceleration of embedded bock in both Lagrange and ALE simulations
- Noise in Lagrange explosive fill formulation acceleration trace due to inability of fill to properly flow/deform around embedded brick and resulting contact algorithm chatter
  - Acceleration trace noise significantly reduced in ALE simulation as these physics are captured better
  - Improvement over Lagrange formulation



ALE Methodology with Heavy Embedded Brick

ALE technique for explosive fill with embedded solid objects able to handle large explosive fill deformations and predict local fill shear

- Stability and capability of method provides notable advantage over Lagrange formulation for modeling embedded scenarios
- Potential for use in simulation-based embedded system explosive fill damage predictions
- Simulation results and predictions heavily tied to explosive fill material model
  - Continued need for validated explosive fill material models



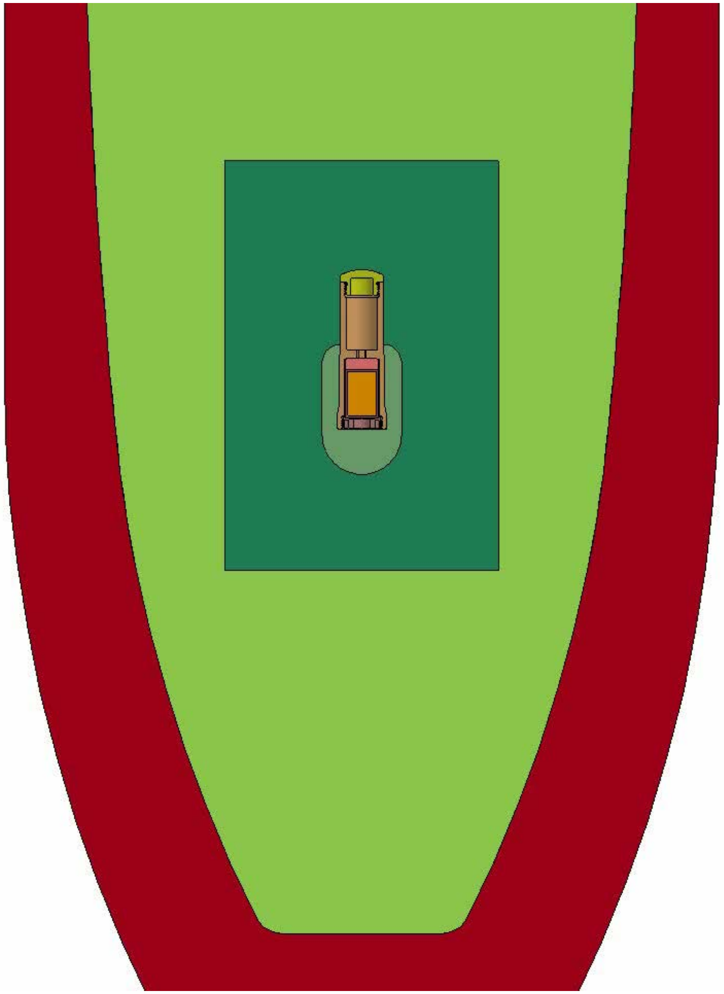
Real World Design Application

Recorder for Explosive Acceleration and Pressure Response (REAPR)

ALE technique used to analyze ARA's embedded REAPR during design effort

- Aided in structural survivability analysis of REAPR development
- Provided confidence that REAPR capable of withstanding pressure loads in excess of 40,000 psi
- Used to provide pretest predictions for upcoming hard-target penetration tests

REAPR design has been finalized, manufactured and in process of being fielded



Conclusions

An ALE formulation for the explosive fill for use with embedded systems is a viable option in LS-DYNA

- Provides good agreement with results provided by legacy Lagrange modeling techniques
- Captures physics required to perform structural analysis on systems embedded in explosive fill
- Removes possibility of simulation termination due to mesh distortion
- Proven to be immensely valuable for structural analysis and design of embedded systems
- Comes with a runtime cost compared to Lagrange formulation – ALE domain dependent
- Actively being used in structural design analysis of explosive fill embedded fuze firesets

Questions?