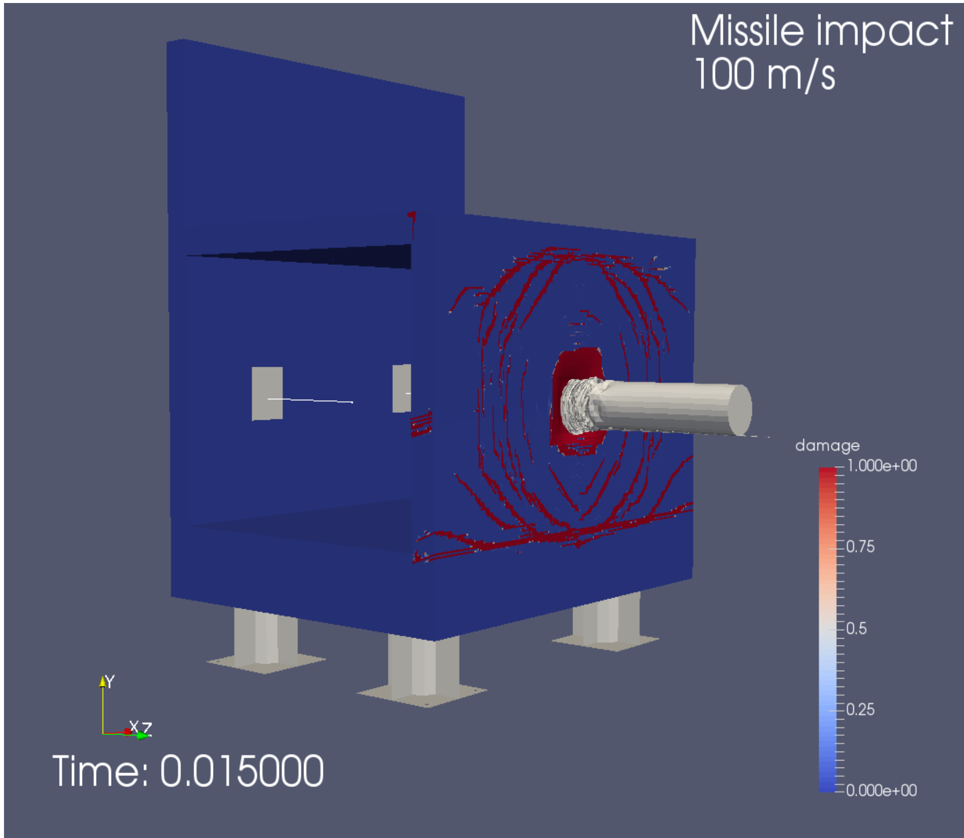
SAND2017-6001PE

Structural Mechanics Simulations in Support of the IRIS-3 Benchmark

Exceptional service in the national interest

Sandia National Laboratories



IRIS III Phase A Workshop
June 13-15 2017, EDF Lab, Paris, France

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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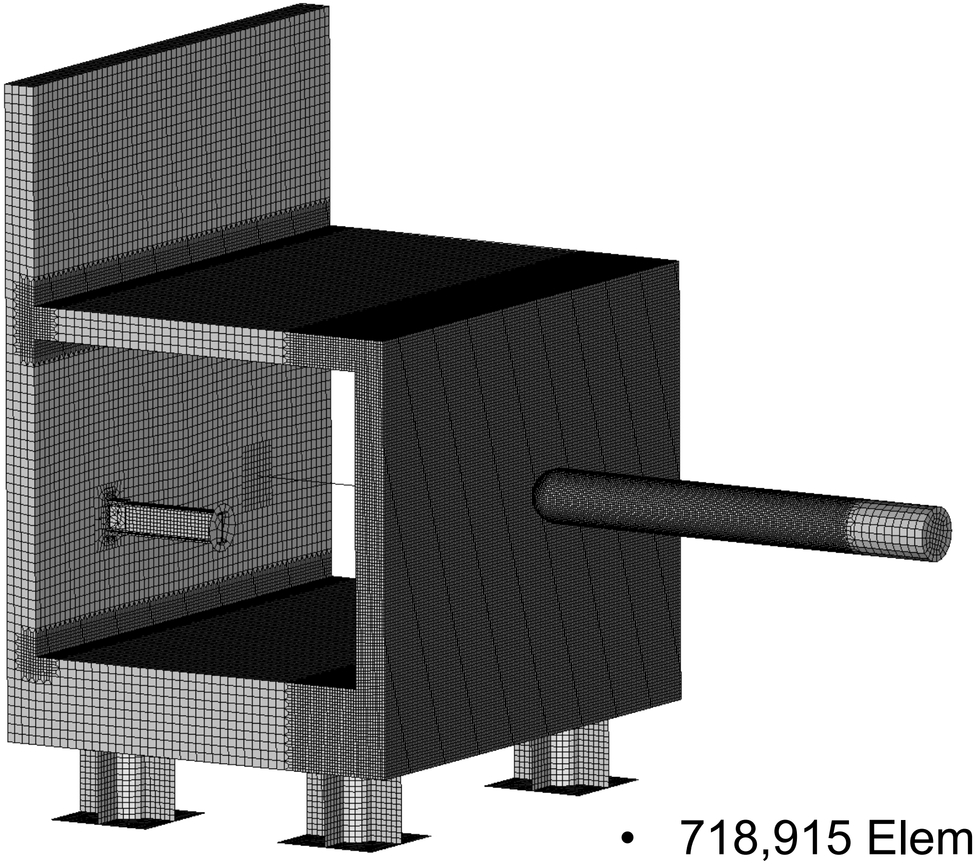
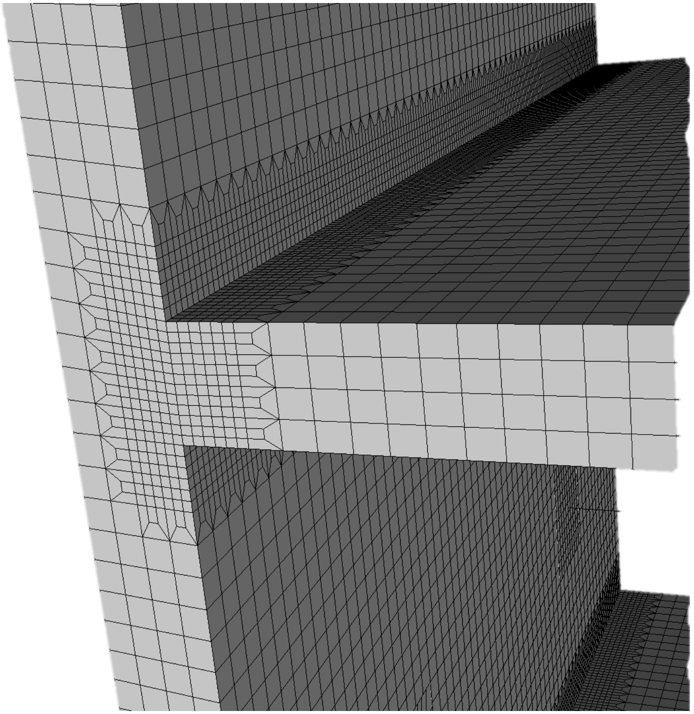
Outline

- Model Geometry and Mesh Overview
- Material Properties and Models
- FEA Computational Information
- Selected Results

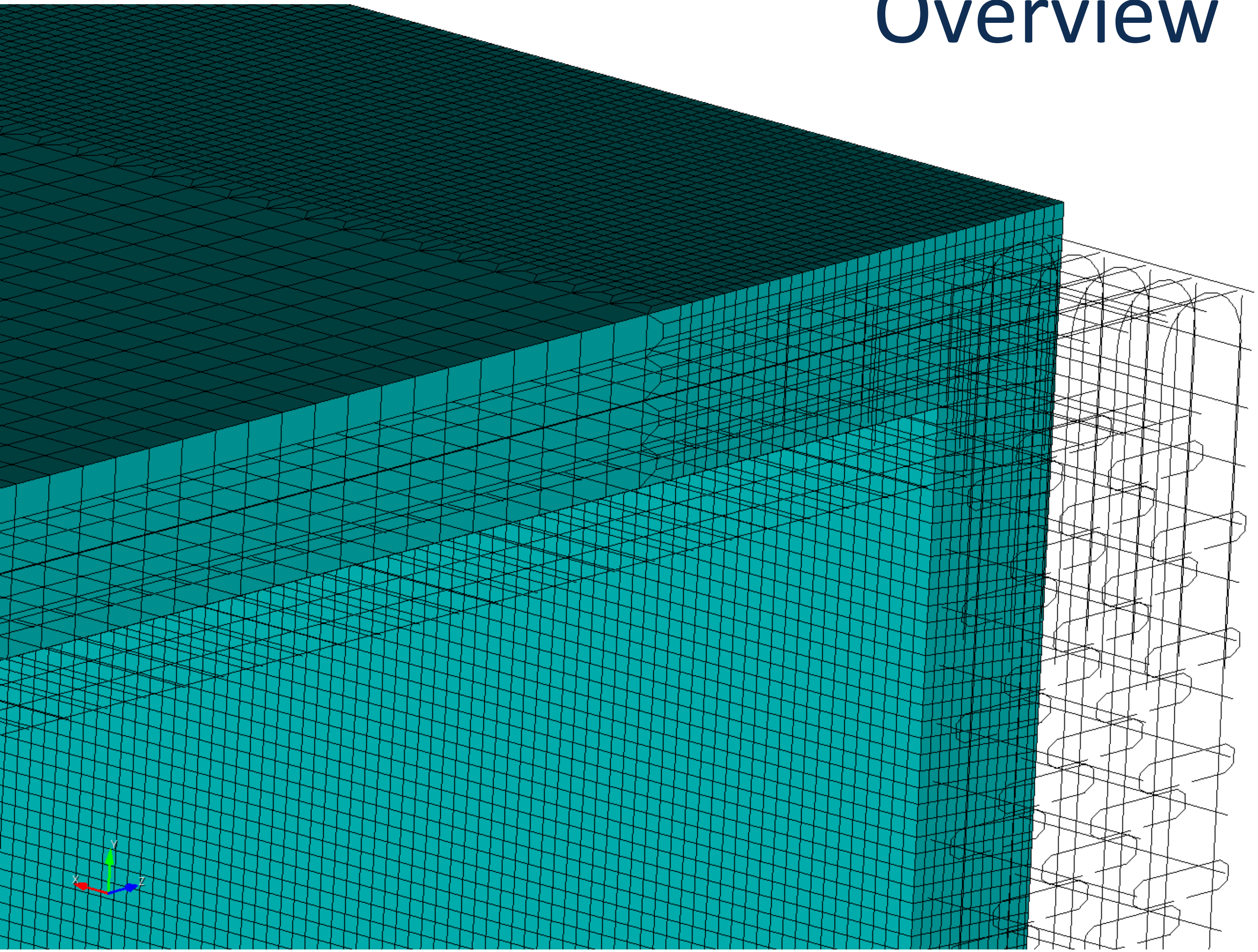
Geometry and Mesh Overview





- 718,915 Elements (8-Node Hexahedral, 4 node Shell, 2 node Beam)
- 772,704 Nodes
- Refined on the impact surface and at joints

Rebar Geometry and Mesh Overview

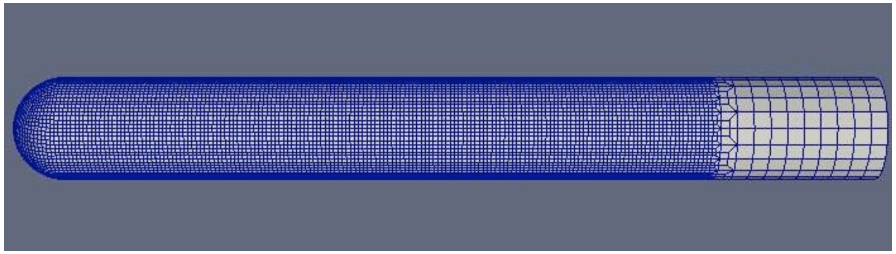


- All reinforcing bars explicitly modeled with 2-node, 6-DOF Beam Elements, circular cross-section
- Rebar elements are ”embedded” in the concrete elements
- 15mm discretization on the impact face, 30mm elsewhere

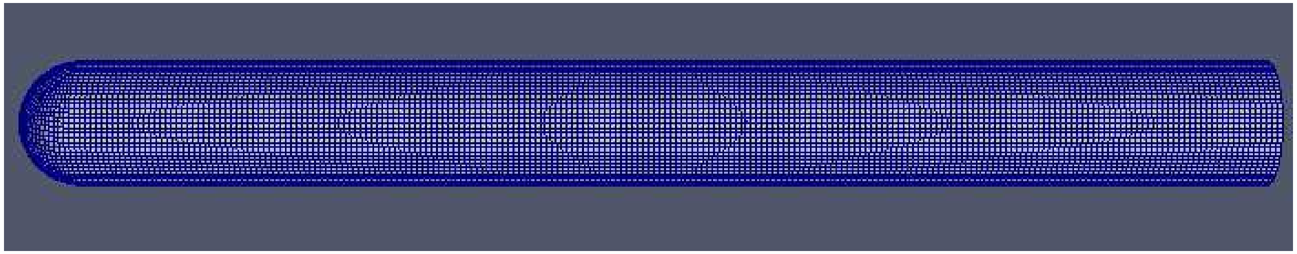
Missile Geometry and Mesh Overview

- Missile tube: shell elements extruded to 1.89mm
- Missile nose: shell elements extruded to 3.00mm
- Missile tail: shell elements extruded to length required to make the total mass 50.1kg

90m/s impact

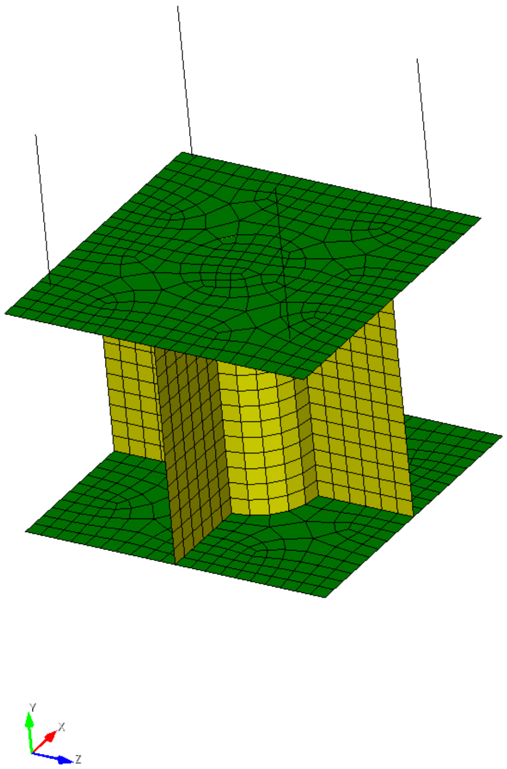


170m/s impact

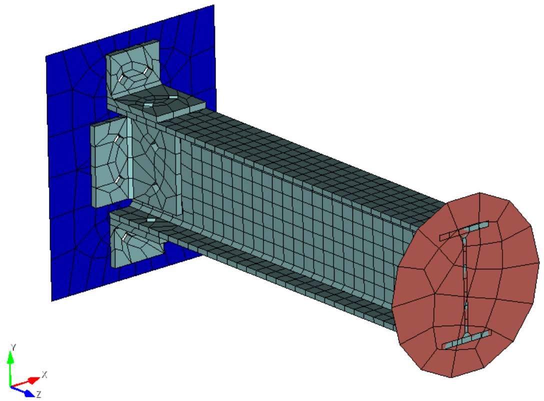


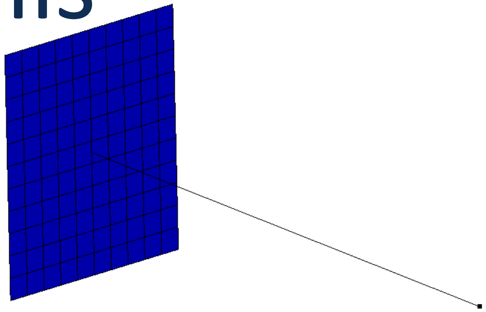
Support Details

- Pedestals:
  - 2D shell elements extruded to proper thickness
  - Bottom nodes fixed in space
- Supporting rods:
  - Beam elements embedded in concrete
  - Bottom nodes fixed to top flange of pedestal



Pseudo-Equipment Details





- Bolted connection:
  - All explicitly modeled (excluding bolts)
  - Bolt holes rigidly fixed at contact points
- Welded connection:
  - Line beam elements
  - Fixed connection to anchor plate
  - Point-mass pseudo-equipment

Material Properties

Material Name	Material Model	Material Application
S355 Steel	Multilinear elastic plastic	Supports (pipe and webbing)
500B Steel	Elastic plastic	6mm diameter rebar
500B Steel 2	Elastic plastic	8mm and 10mm diameter rebar
316L Stainless Steel	Multilinear elastic plastic	Missile
Generic steel*	Elastic plastic	Anchor rods, I-beams, I-beam supporting plates
Concrete	Holmquist Johnson Cook concrete	Concrete

*Similar to S355 steel but without multiple stages in the elastic regime

Holmquist-Johnson-Cook Concrete Model

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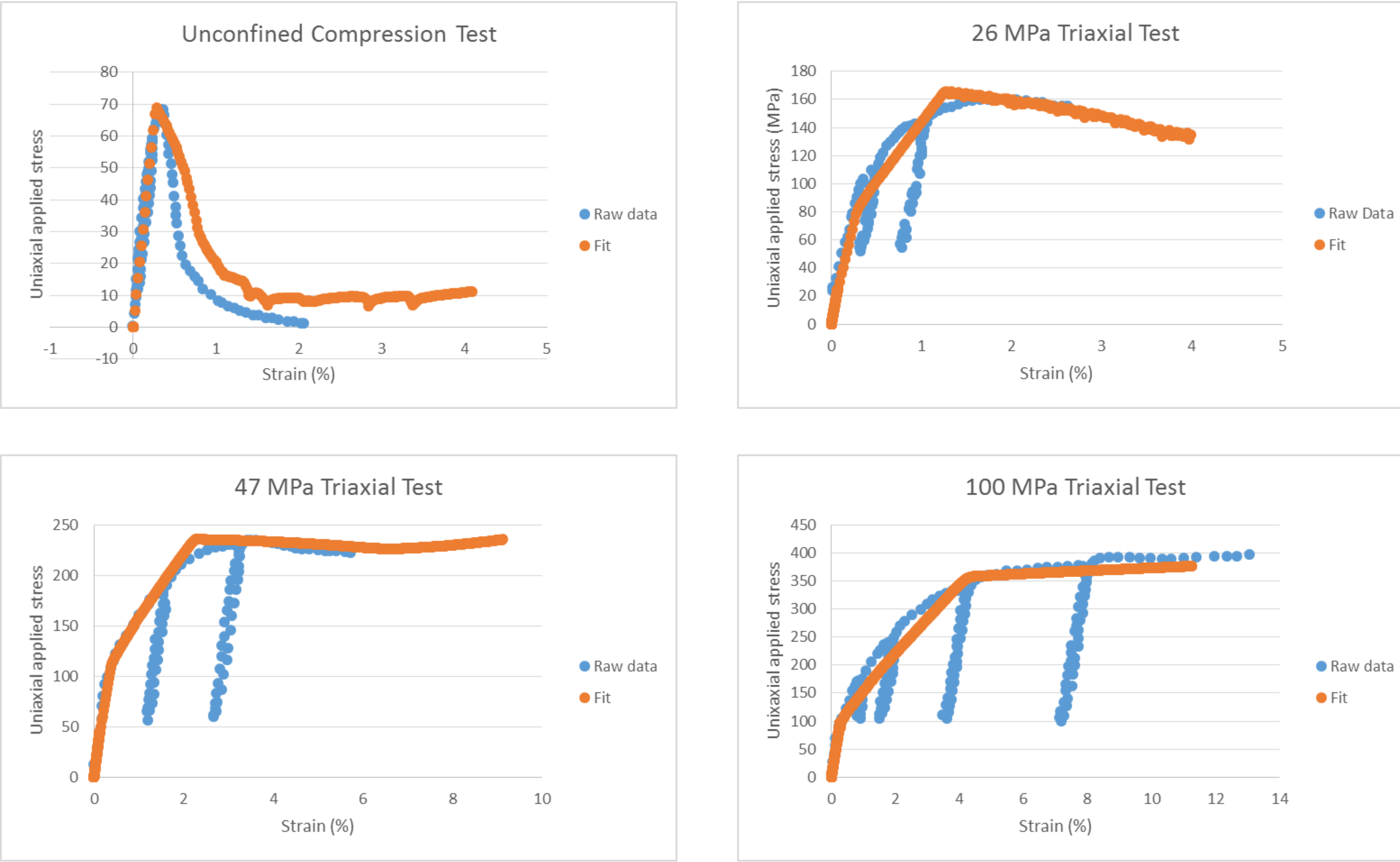
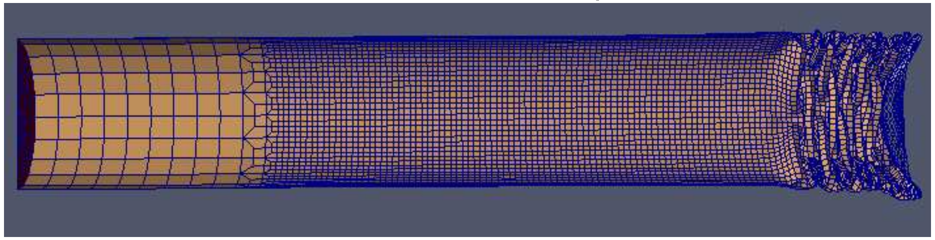


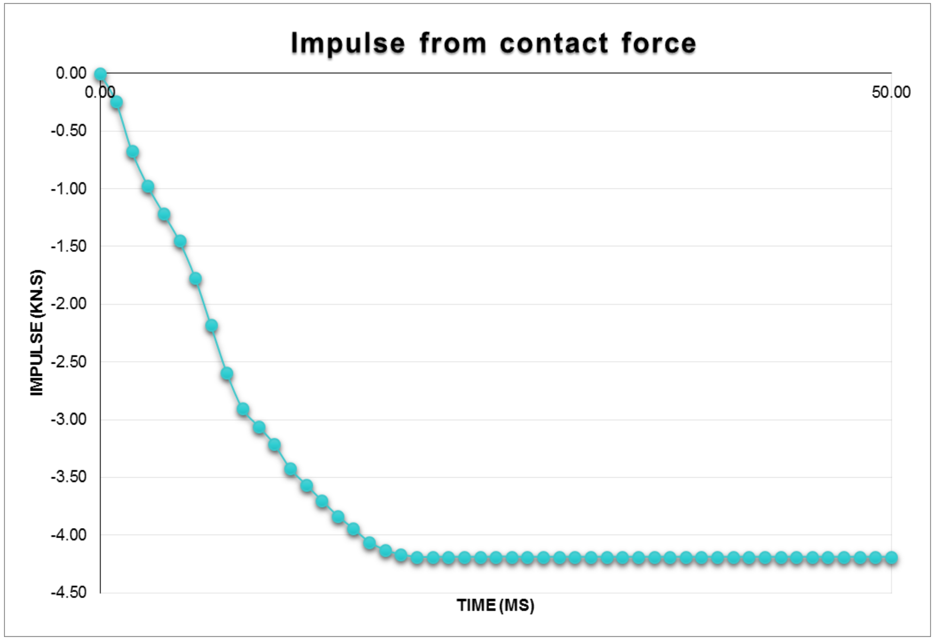
FEA Computational Information

- Explicit time integration scheme
- Sandia National Laboratories code: SIERRA Solid Mechanics
- Critical time step: 6.175e-07 seconds
- Simulation run time on 96 processors:
  - 90m/s missile: 47.5 hours
  - 170m/s missile: 96 hours

90m/s Missile Force and Impulse

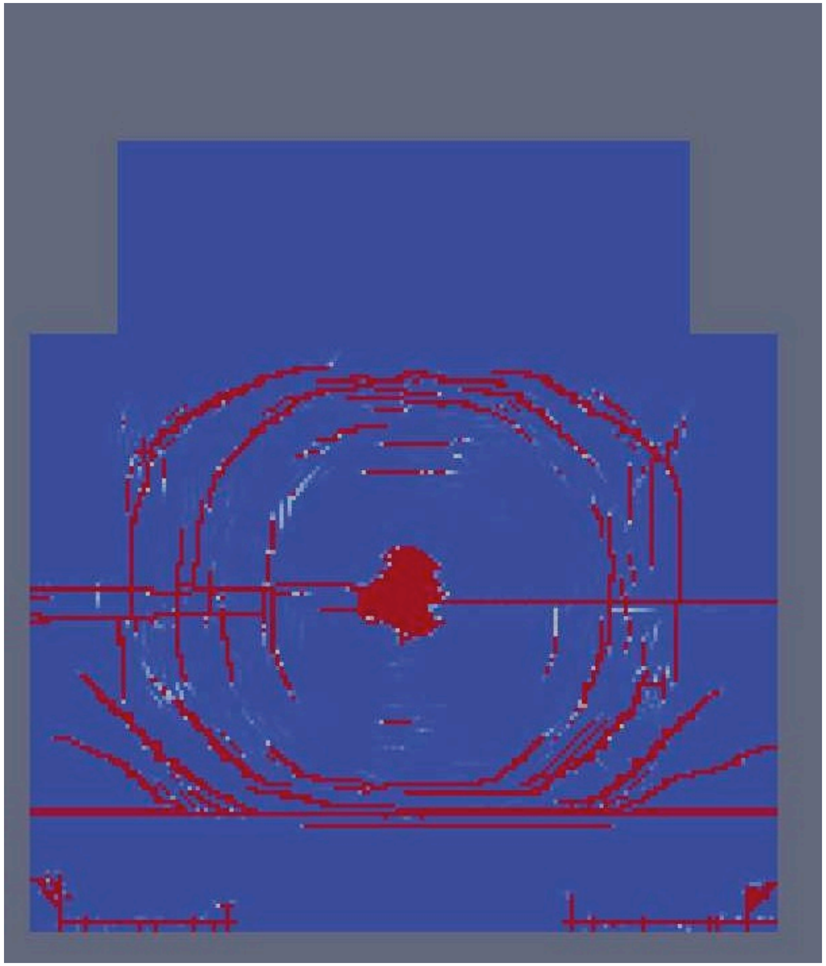
Missile at T_{imp}



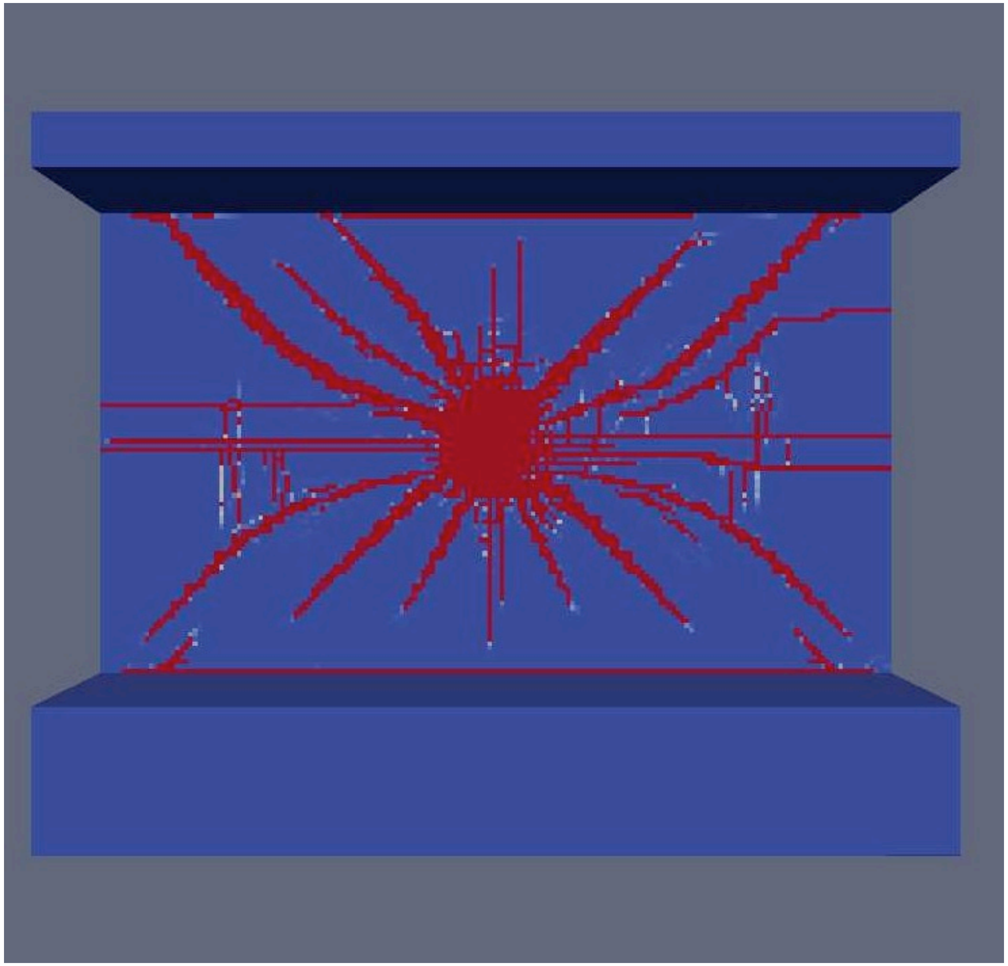


90m/s Missile Damage to Concrete

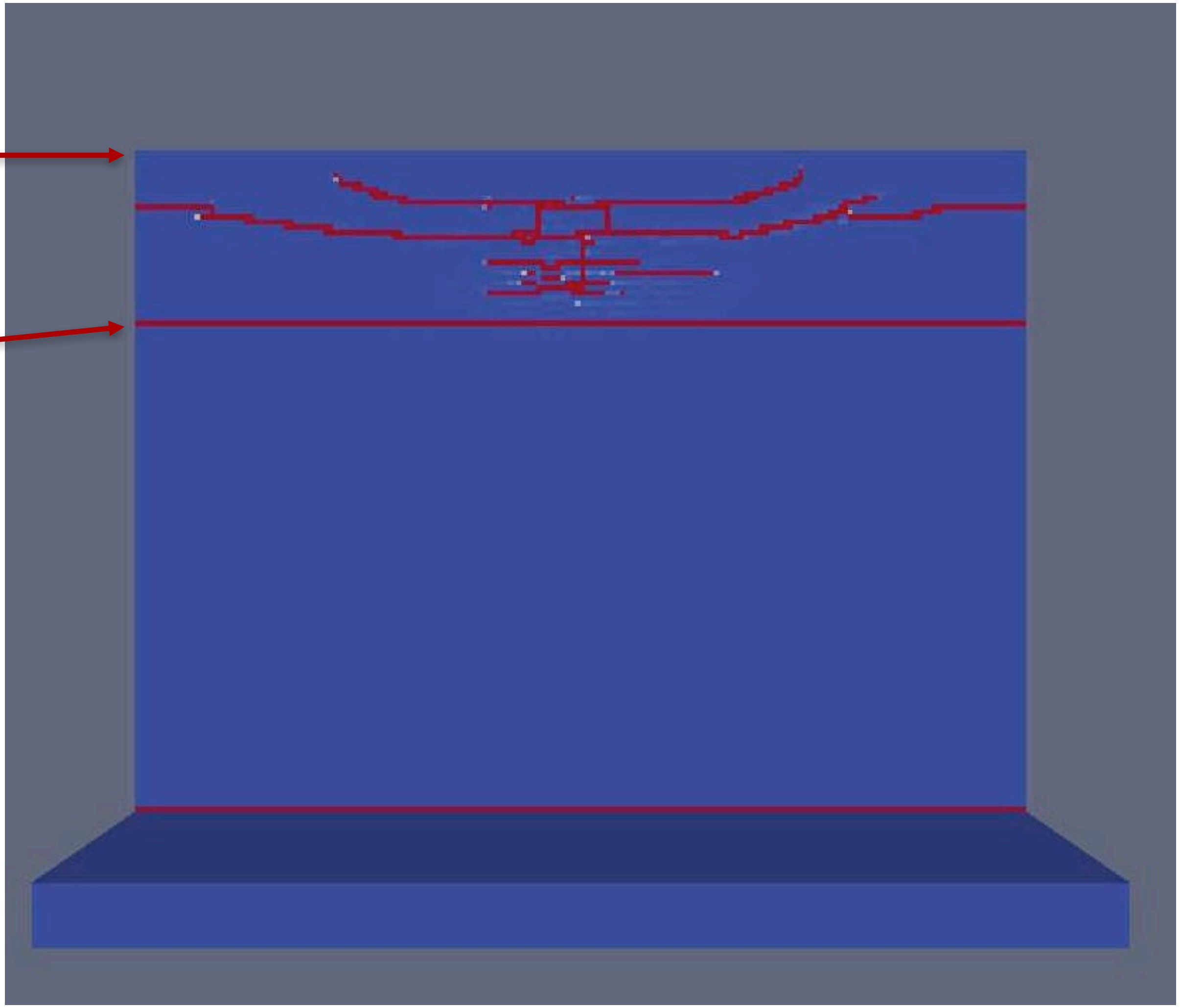
Front face



Back of front face

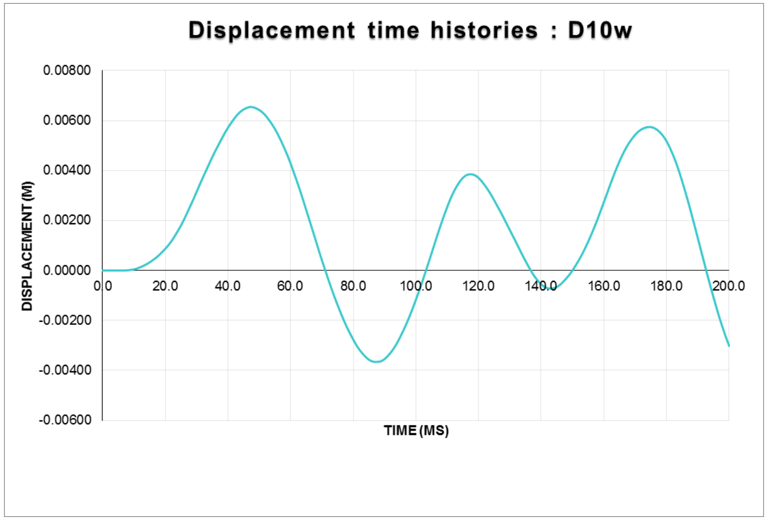


90m/s Missile Damage to Concrete

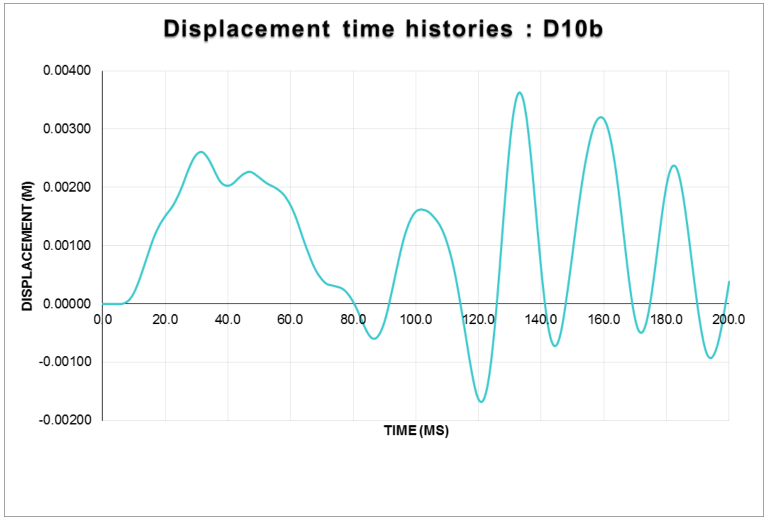


Displacement Time Histories of Pseudo-Equipment

Welded connection



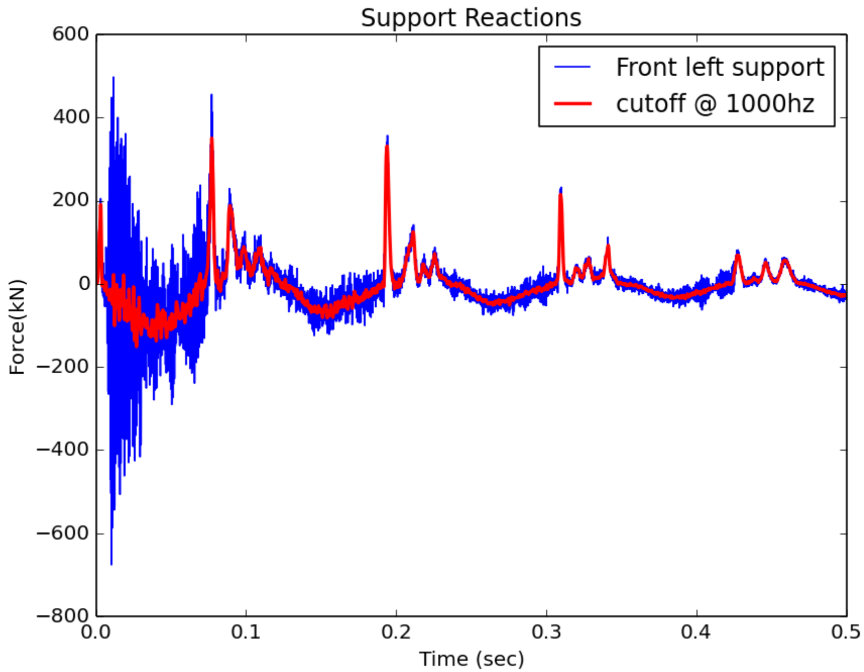
Bolted connection



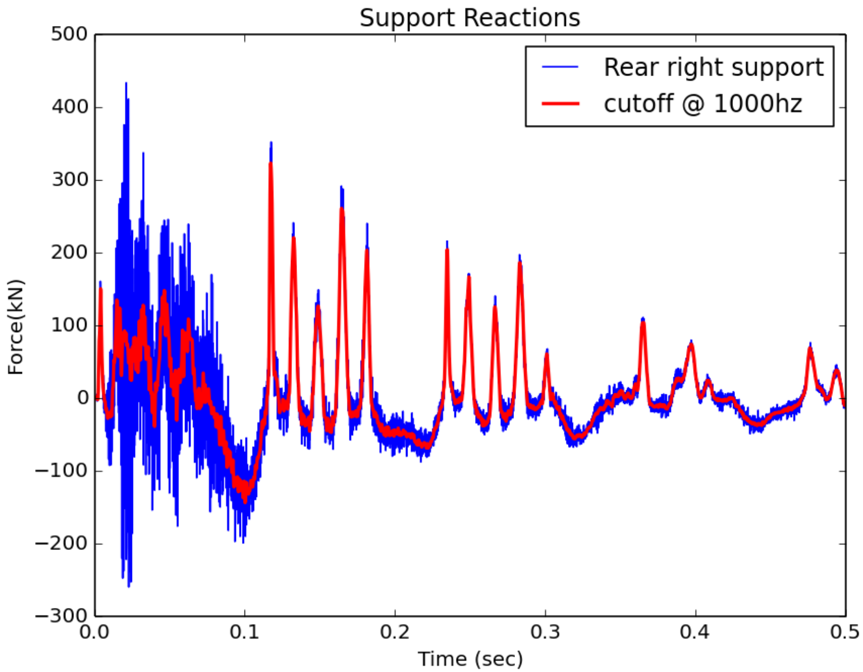
Support Reaction Force

Noise in the data is a result of the missile kinematics. Element failure and folding sends shockwaves through the structure.

Front left

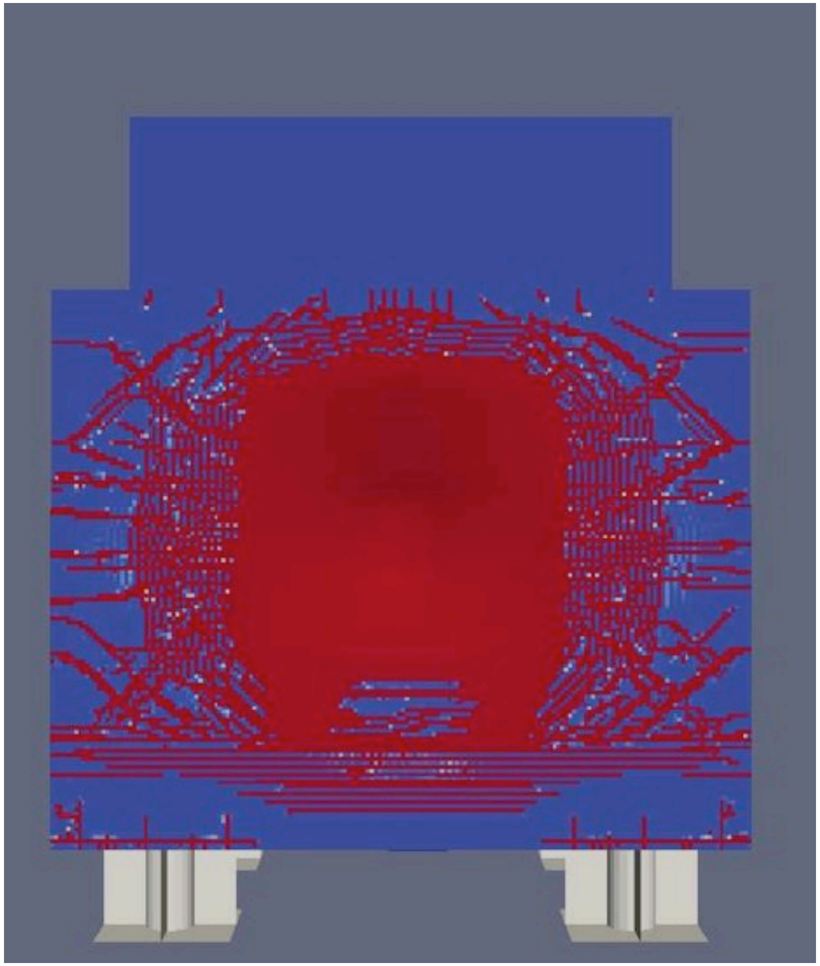


Rear right

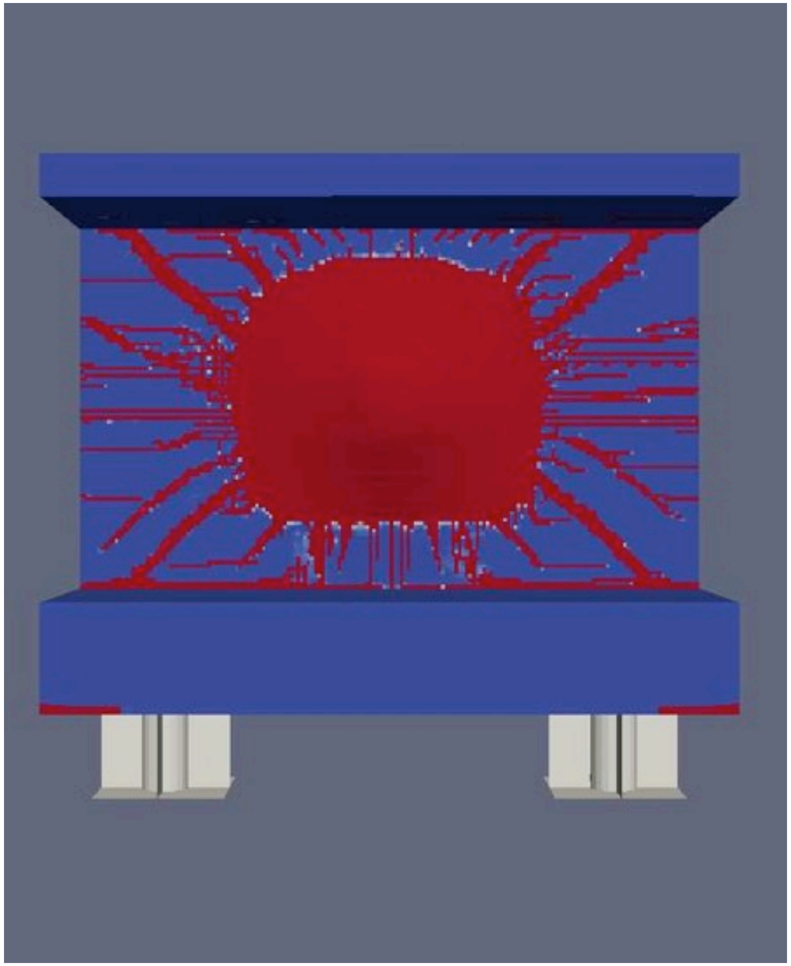


170m/s Missile Damage to Concrete

Front Face

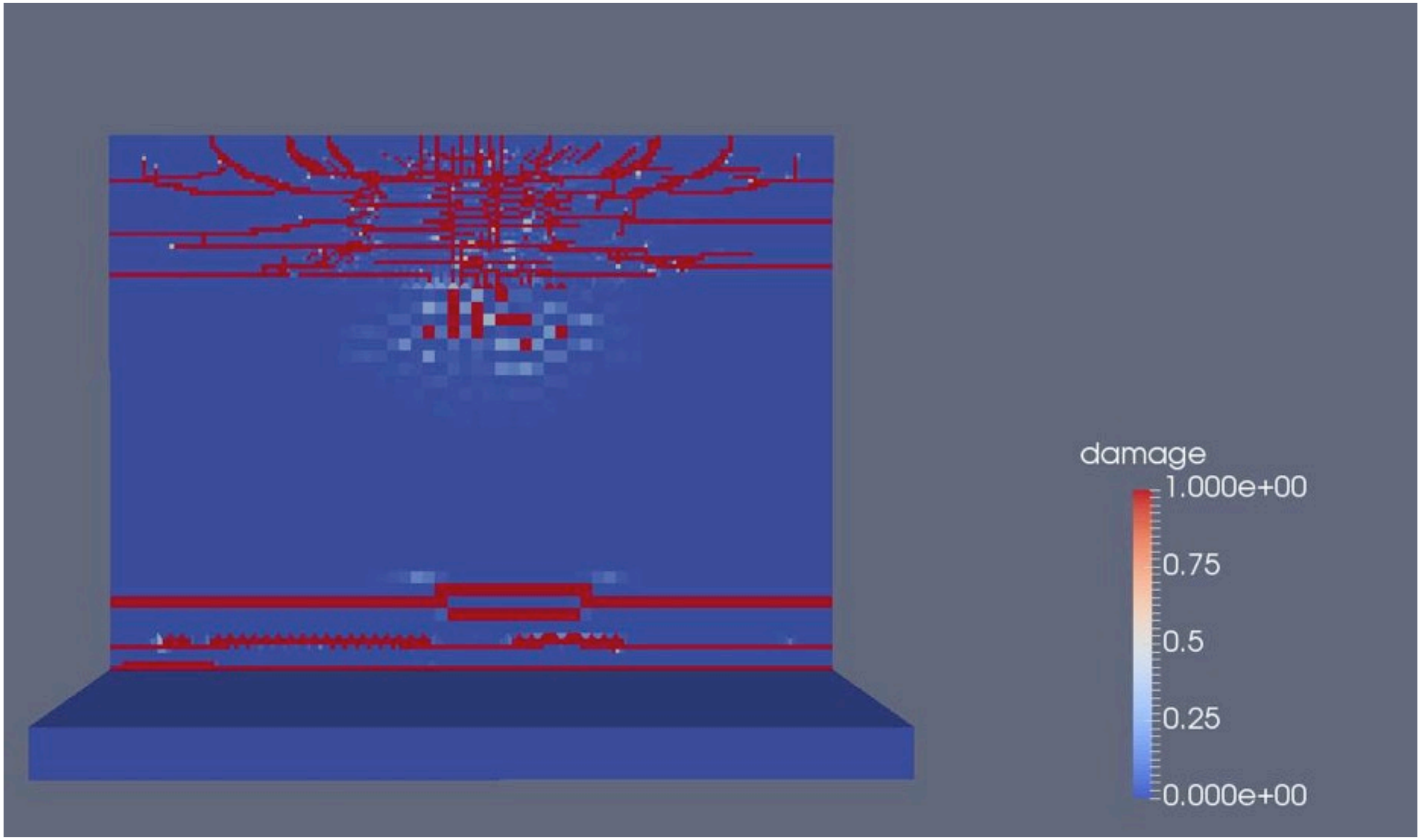


Back of Front Face



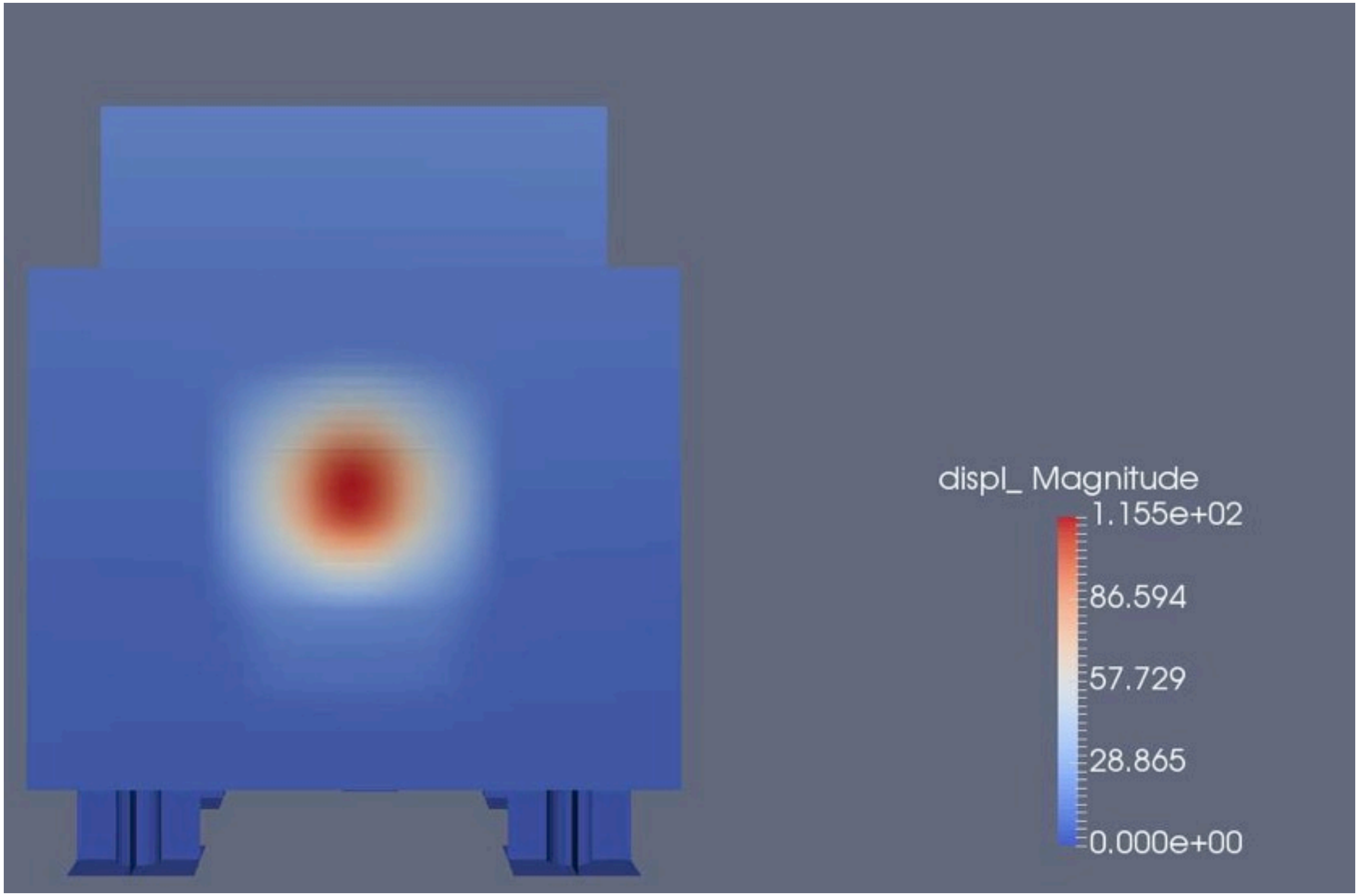
170m/s Missile Damage to Concrete

Top view



170m/s Missile Penetration

Displacement of concrete (final) in mm



Phenomenological Assessment

- Phenomenological equations from Methodology for Performing Aircraft Impact Assessments for New Plant Designs (NEI 07-13)

IRIS III	Velocity:	90m/s	170m/s
Missile penetration depth (mm)		43.7	77.5
Wall thickness required to prevent scabbing (mm)		15.4	65.1
Wall thickness required to prevent perforation (mm)		111	188
Actual wall thickness: 150mm			

Conclusions

- Material models correctly represent physical material behavior
- A coarse mesh refined in key zones is optimum for results and computational expense
- The 90m/s missile did not penetrate, but the 170m/s missile did penetrate
- The welded I-beam connection is more rigid than the bolted I-beam connection
- Acceleration and force data is noisy due to structural vibrations caused by element folding in the impacting missile