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Sandia National Laboratories/U.S. Nuclear Regulatory Commission: EMU Simulations

OECD/NEA IAGE Workshop on IRIS 2010 Benchmark on Improving Robustness Assessment Methodologies for Structures Impacted by Missiles

NEA Headquarters, 13-15 December 2010

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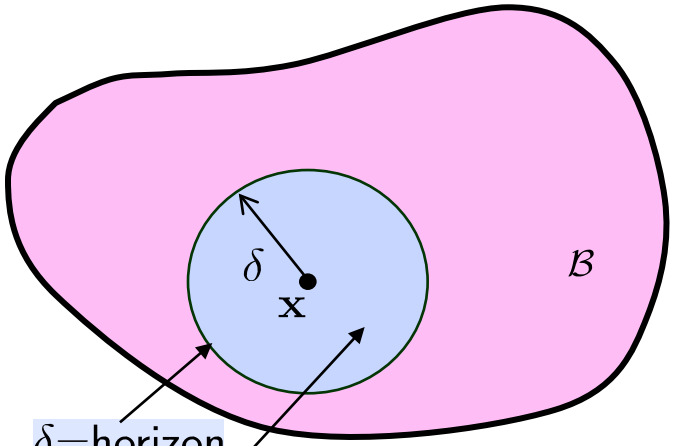
Outline

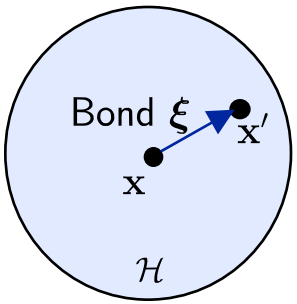
- EMU Background
- Computational Strategy
- Assumptions and Technical choices
- Drawbacks and Advantages of path chosen
- Improvements for future calculations

EMU Background

- Sandia developed research code that predicts deformation and failure in bodies and structures subjected to dynamic loading
- Uses the peridynamic theory of solid mechanics
  - Replaces all partial differential equations of conventional continuum mechanics with integral equations.
  - Integral equations remain valid regardless of fractures or discontinuities.
  - Cracks develop as a result of the equations of motion and the material model and propagate in energetically favorable directions
  - Does not use stress intensity factors, separation laws, or element failure criteria
  - EMU is meshless Lagrangian code

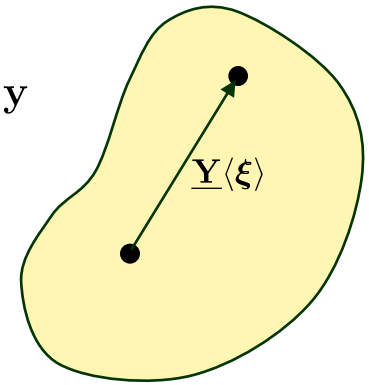
EMU Background



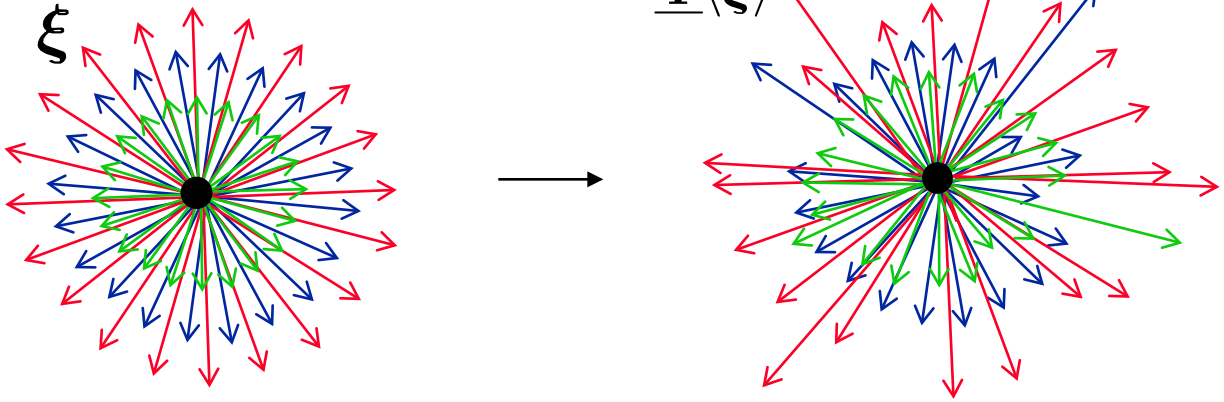


Undeformed family of $\mathbf{x}$

Deformation $\mathbf{y}$



Deformed family of $\mathbf{x}$



Undeformed bonds connected to $\mathbf{x}$

Deformed bonds connected to $\mathbf{x}$

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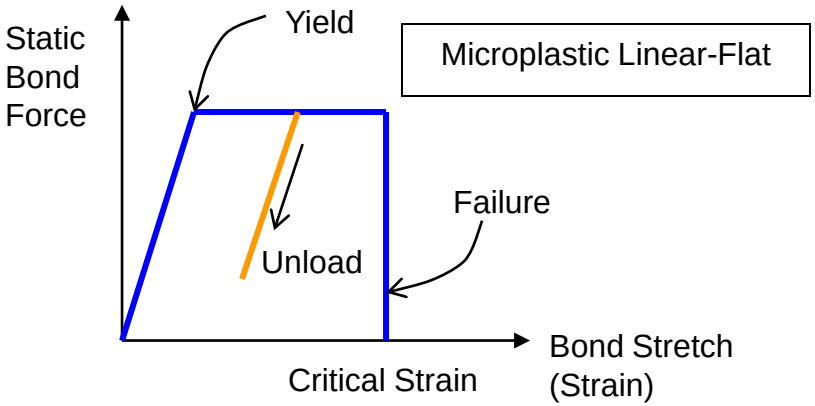
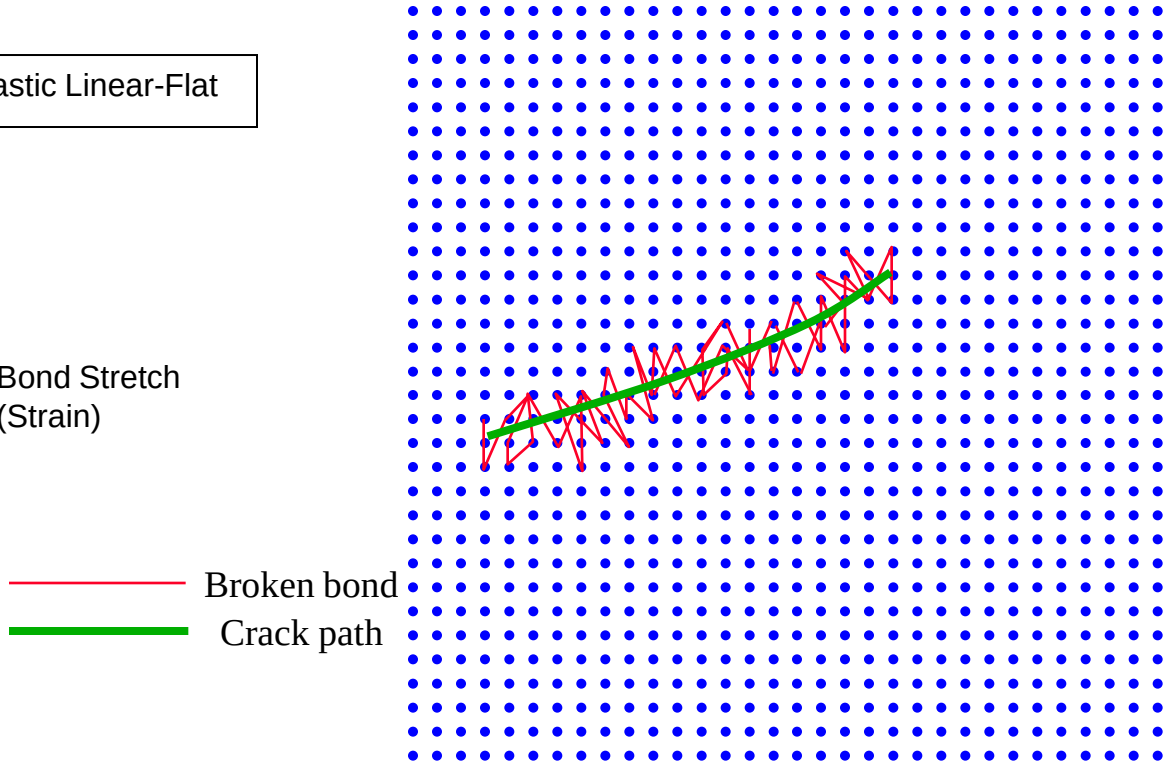
EMU Bond Behavior





When a bond breaks, its load is shifted to its neighbors, leading to progressive failure.

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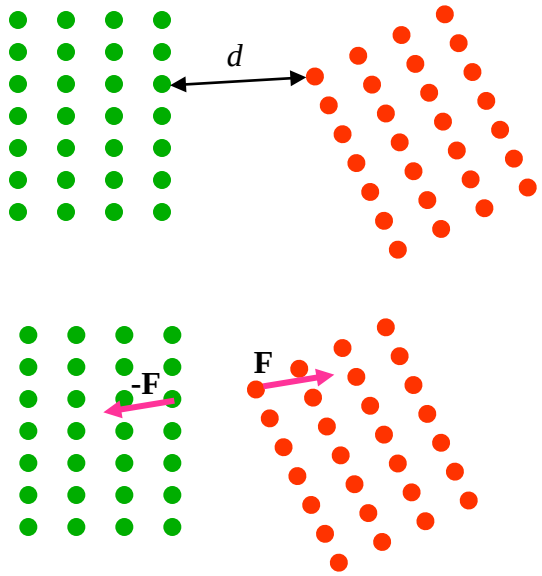
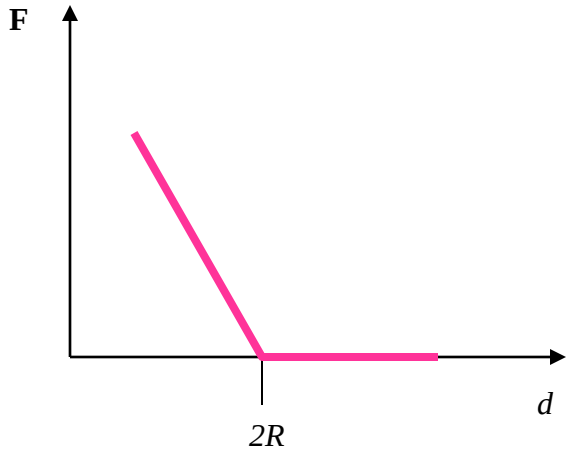
EMU Contact

Emu contact algorithm applies repulsive forces to any pair of nodes that get too close to each other





d = current distance between any two nodes
R = node radius (constant, typically set to grid spacing / 2)
F = contact force

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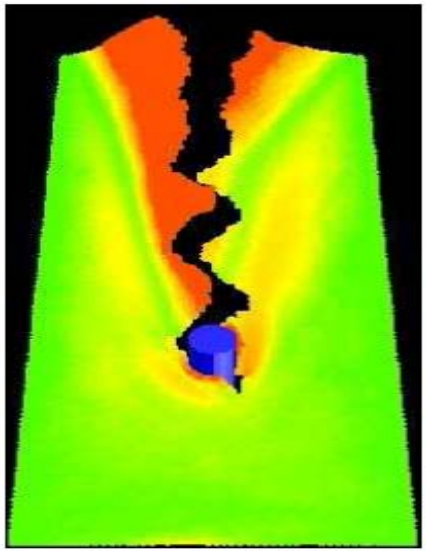
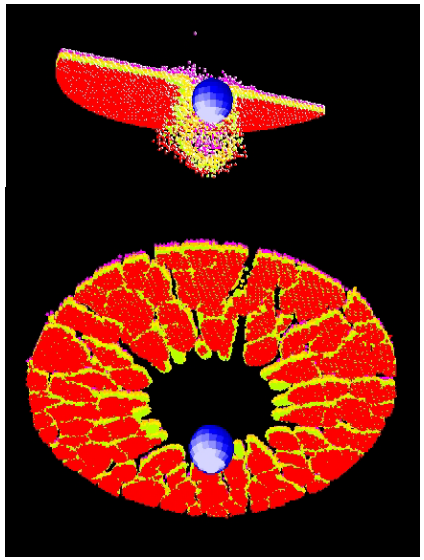
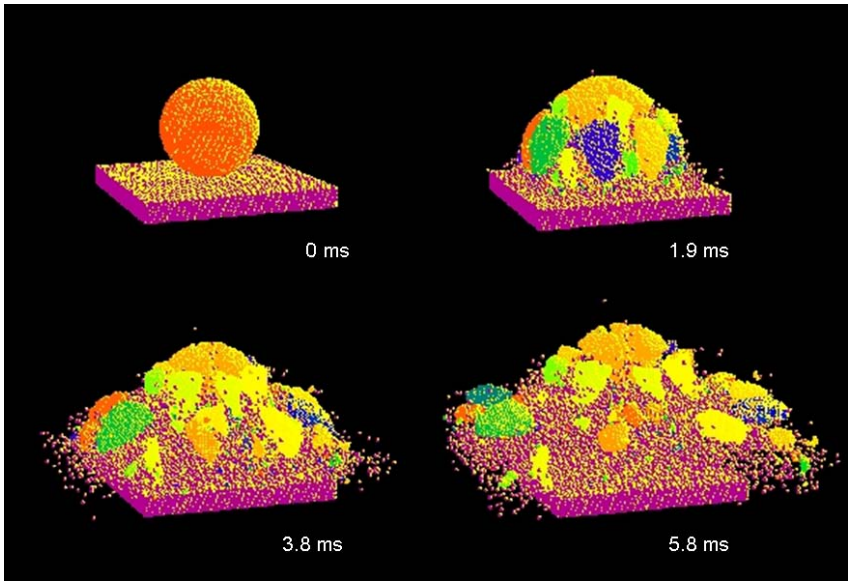
EMU Analysis Examples



Tearing instability



Impact and fragmentation



concrete sphere impact against a rigid plate

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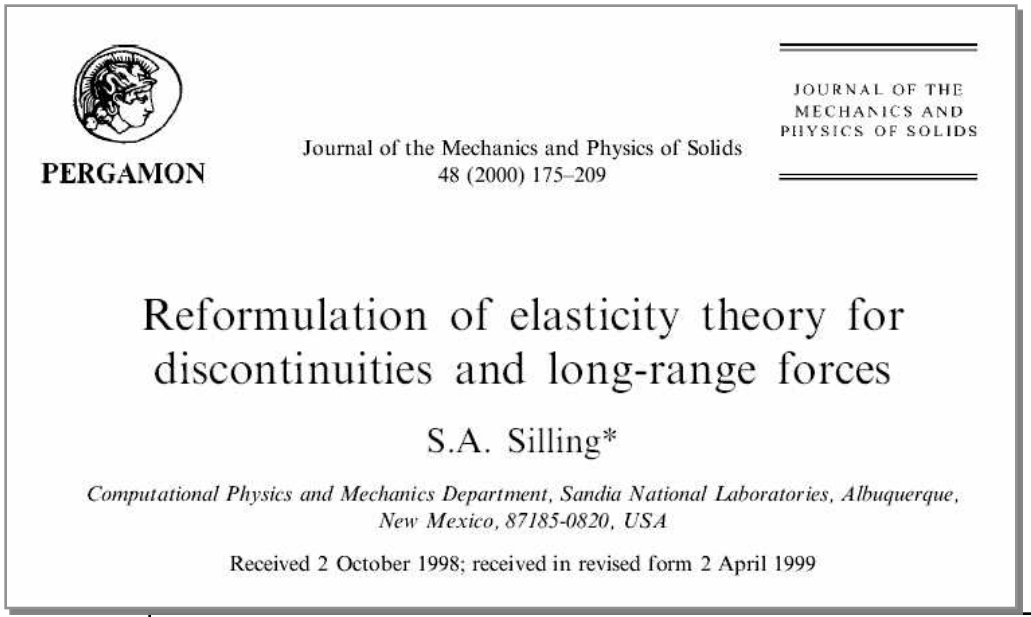
Peridynamics References



PERGAMON

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Reformulation of elasticity theory for discontinuities and long-range forces

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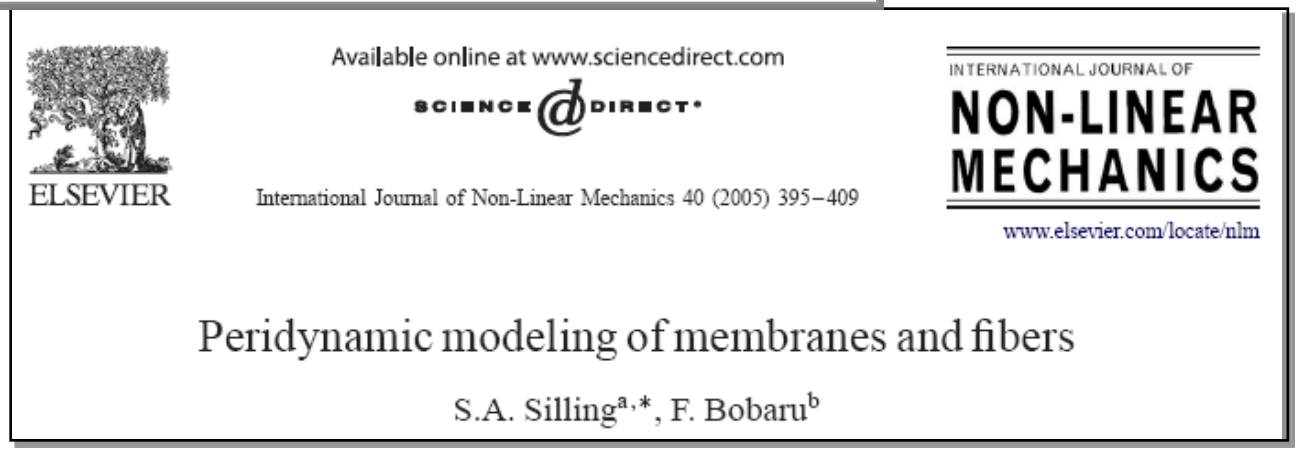
Silling and Askari, "A meshfree method based on the peridynamic model of solid mechanics", Computers and Structures, 83 (2005), 1526-1535



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Peridynamic modeling of membranes and fibers

S.A. Silling[a,*], F. Bobaru[b]

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Computational Strategy

- EMU Simulation Tool
- Explicit Model for Missile Impactor
- Explicit Concrete and Steel Reinforcing Bars
- Full model symmetry (Meppen II-4, Flexural and Punching Mode test)
- Concrete Material Model correlated
- Steel Material Model correlated
- Test support structure partially included to provide boundary conditions

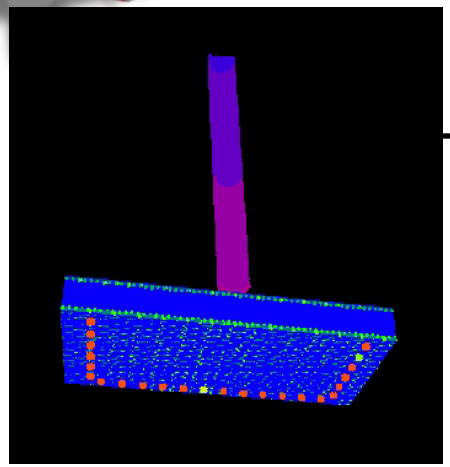
EMU Simulation Tool

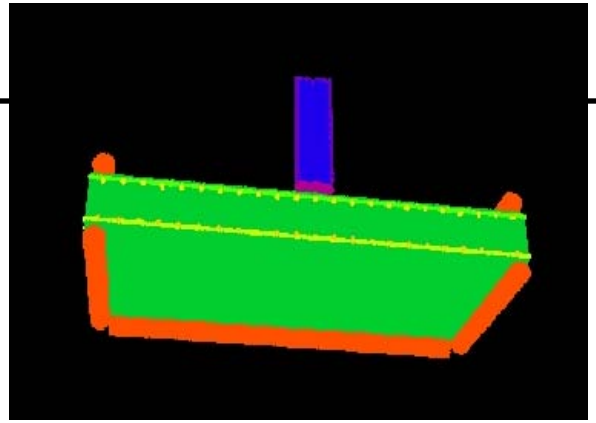
- EMU simulations executed using version 2.6.32 on 32 processors on Sandia's Red Sky computing cluster
- Red Sky (unclassified partition) is a collection of 2800 dual socket/quad core nodes (over 22,000 cores)
- Run times for each simulation did not exceed 16 hours

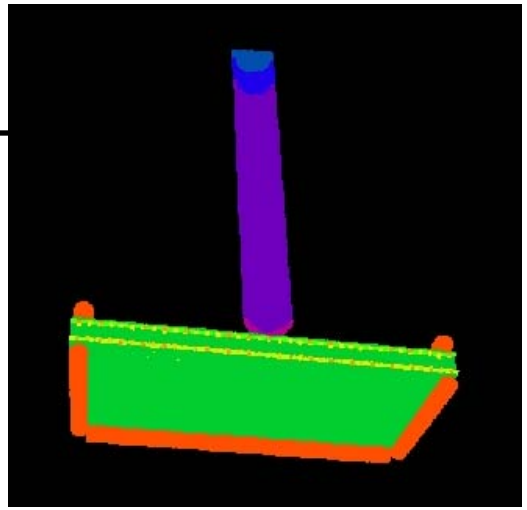
Concrete and Steel Reinforcing Bars

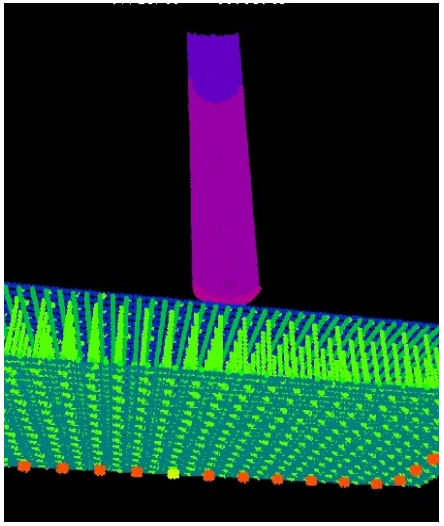
- The concrete slab was modeled with a cubic lattice of nodes with a 40mm spacing for Meppen and 15mm for Flex/Punch
- Steel reinforcing bars inside the concrete slab were explicitly modeled with a string of nodes
- Reinforcing nodes also connected to the concrete nodes with peridynamic bonds
- Simple microplastic material model used for concrete and rebar (more sophisticated models available, but significant experience with the microplastic model)
- Concrete yield stress of microplastic model set to unconfined compressive stress (with exception of the Flex/Punch stress)
- Rebar steel yield stress set to plastic limit stress, then perfectly plastic
- Failure modeled with bond breaking using a failure strain

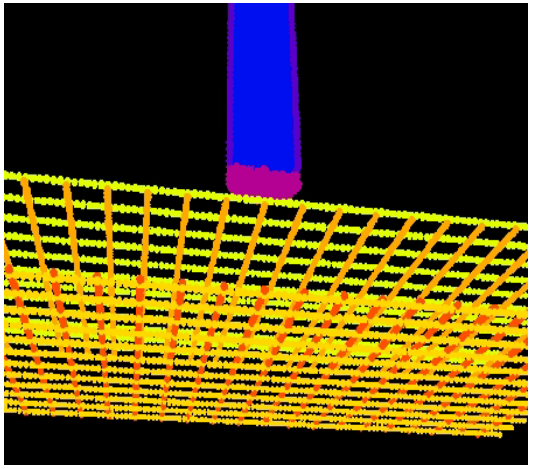
Concrete Slab and Steel Reinforcing Grids

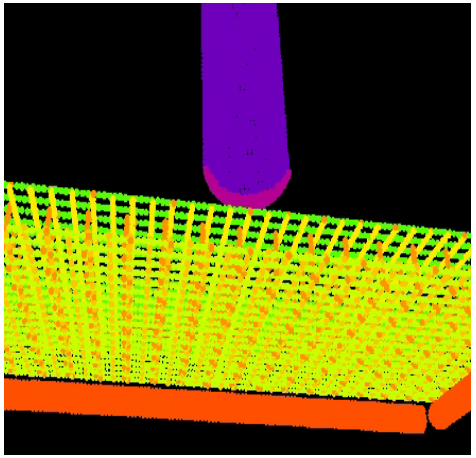












Meppen:
Full Symmetry Model
Stirrups

Punching:
Full Symmetry Model
No Stirrups

Flexural:
Full Symmetry Model
Stirrups

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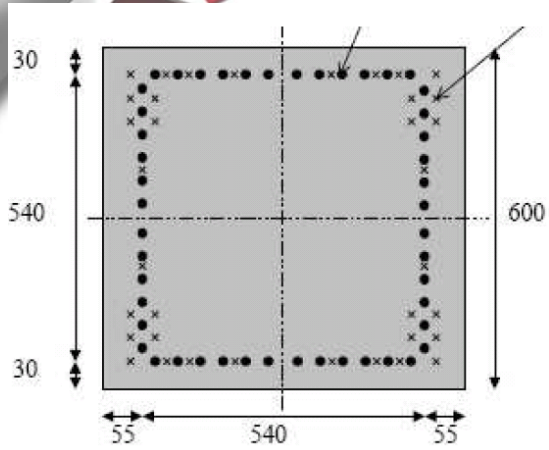
Missiles

- Explicit model of impacting missiles used for all three analyses
- Microplastic model used for missile material
- 3 degree angle of attack used for Meppen and Flex and 1 degree angle of attack for Punch
- Fill material used for Punching mode missile

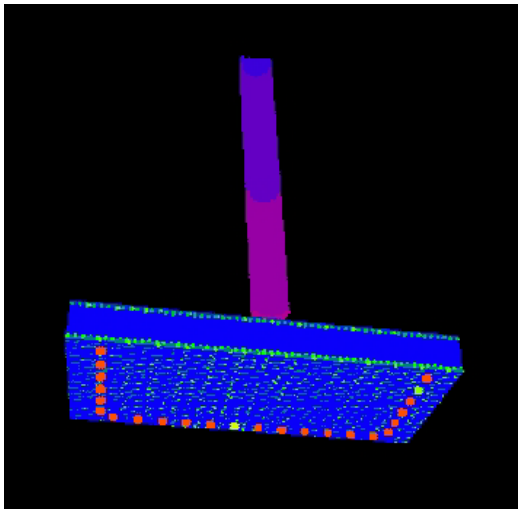
Boundary Conditions

- **Boundary conditions were applied through partial modeling of the support structures**
- **For Meppen, the loads cells were modeled rigid, but with elastic interactions between the rigid cells and the panel**
- **For the Flex and Punch, rigid rollers were models along the perimeter. In addition, the material in the slab in contact with the rollers was not allowed to undergo damage**

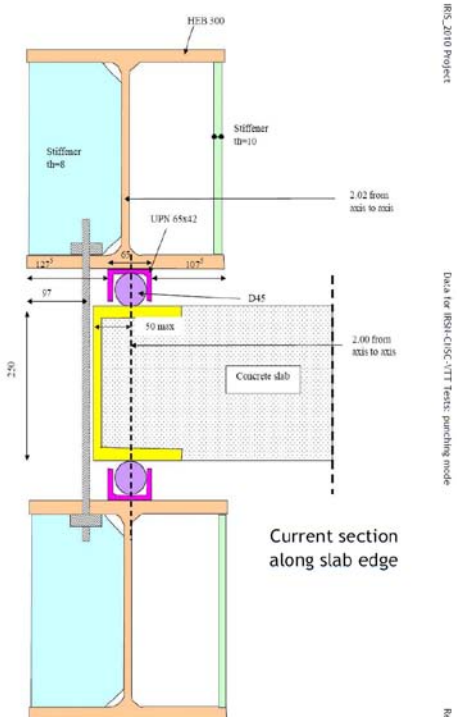
Boundary Conditions (continued)



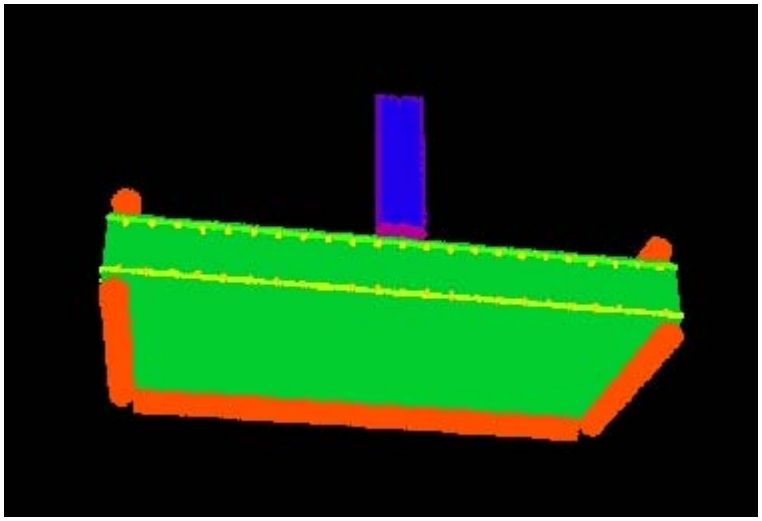
Meppen II-4 Test: Support Points (black dots) on rear of target, z = -0.35 m



Meppen modeled with Red points identifying rigid load cell locations



Punching Test Frame (Flexural Test Frame was similar)



Flex and Punch modeled with rigid rollers around the perimeter

Punching Model and Flexural Model Target BC nodes

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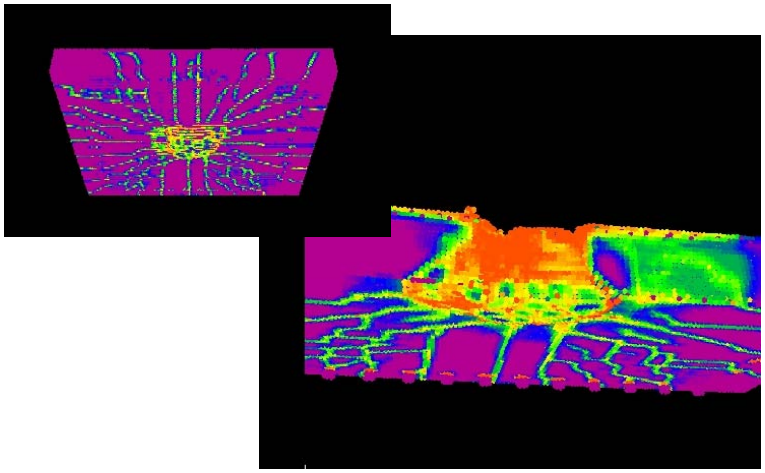
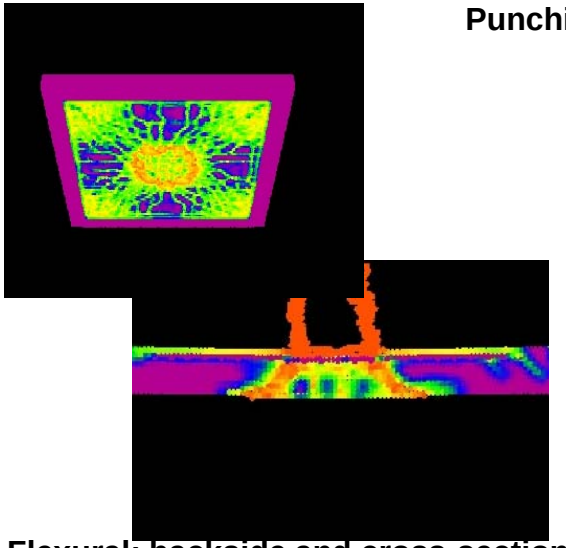
Assumptions and Technical Choices

- Simple microplastic material model used for all materials
  - Experience
- Reduced concrete strength used for Flexural and Punching
  - Extremely high for concrete
  - Experience
  - Thin panels
- The thickness of the Flexural and Punching tests are thinner than most concrete panel experience with EMU (especially the Flex)

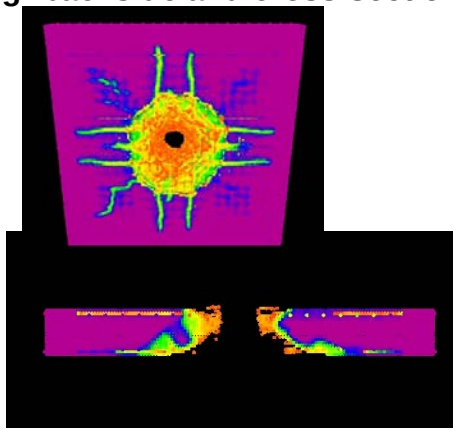


Meppen: backside and cross-section



Flexural: backside and cross-section

Punching: backside and cross-section



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Improvements for Future Calculations

- Revisit analyses and calibrate to Meppen, Flexural, and Punching
- Examine more sophisticated material models