State-of-the-Art Technological Developments in Concrete – Computational Modeling, Emphasis on Blast Effects

Daniel G. Linzell
Associate Professor
Department of Civil and Environmental Engineering
Penn State University

Acknowledgements

- PSU
  - Faculty - James Anderson, Lyle Long, Barry Scheetz, Andrea Schokker
  - Grad Students – Emre Alpman, Abner Chen, Andrew Coughlin, Eric Musselman, Richard Myers, Thara Viswanath
- Sponsors
  - PSU Applied Research Lab
  - Office of Naval Research
  - AFRL
  - APCI
  - Ogden Tech.
  - Kontek Industries

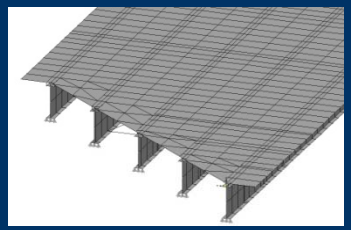
Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

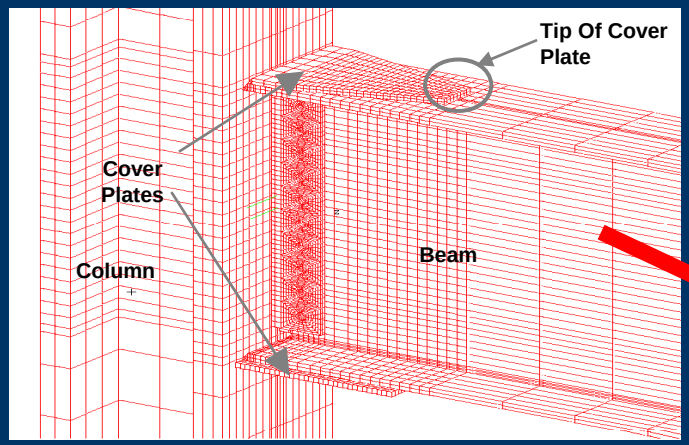
Background – Finite Element Analysis (FEA)

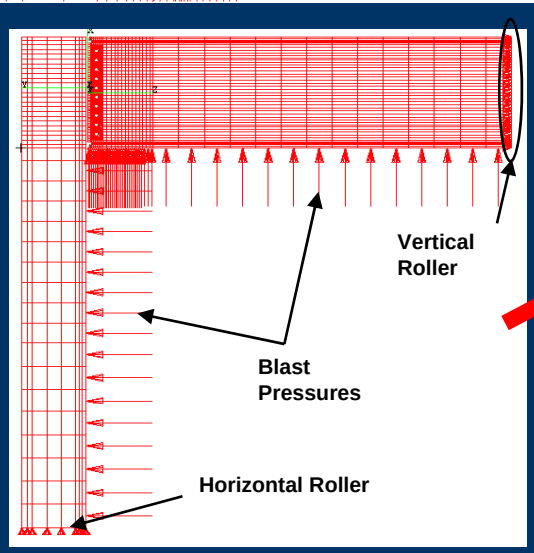


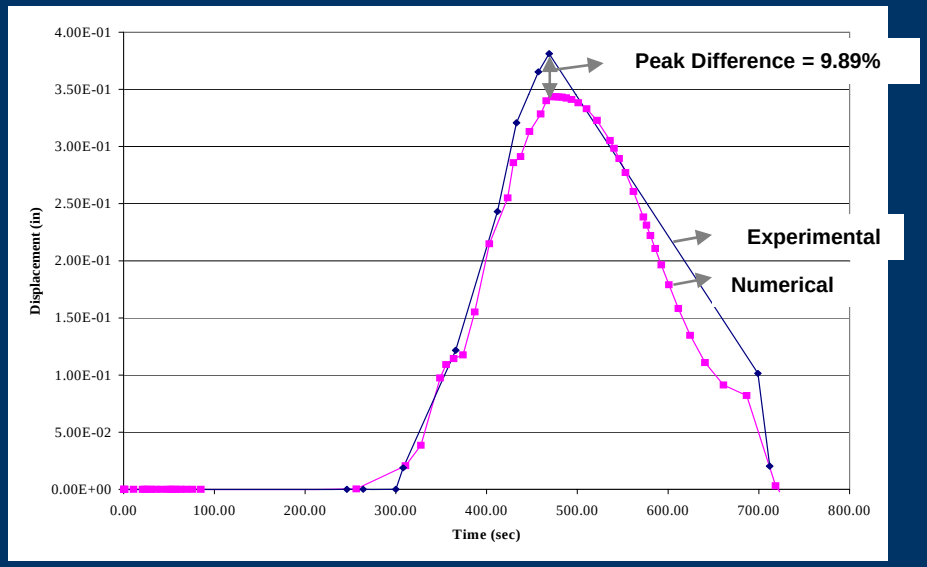
- What is FEA?
  - Computer-based numerical technique (1940s/50s)
  - Calculating strength and behavior of engineering structures
    - Deflection, stress, vibration, buckling, many other items
    - Small or large deflection effects
    - Elastic, inelastic, plastic material response

FEA

- Structure is broken down into many small simple blocks or elements
  - Behavior of individual element described with relatively simple equations
  - Element behavior equations combined
    - Large set of simultaneous equations describing behavior of whole structure (EASY FOR PCs)
  - After solving equations, extracts behavior of individual elements
    - Used to get stress, deflection, etc. anywhere

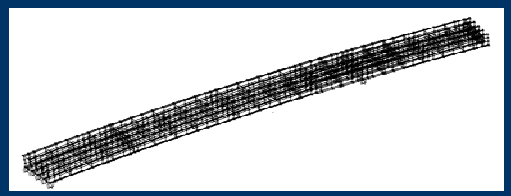

Tip Of Cover Plate
Cover Plates
Column
Beam


Vertical Roller
Blast Pressures
Horizontal Roller

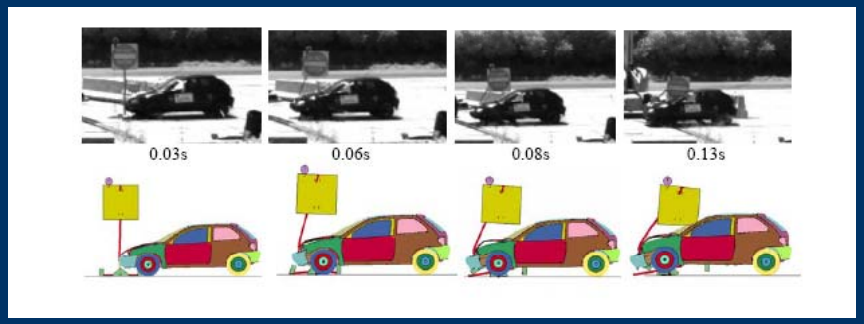

Peak Difference = 9.89%
Experimental
Numerical
Displacement (in)
Time (sec)
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00

FEA

- Why useful?
  - Can evaluate behavior of complex structures using systematic, proven approach
    - Fewer assumptions built into analysis?
  - Relatively efficient – allows for parametric/optimization studies relatively efficiently
  - Able to be performed using basic PC platforms
    - Economical? Depends.

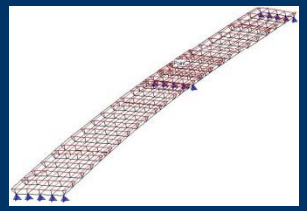


FEA



- Types of Analyses?
  - Discussed earlier
    - Deformations – large vs. small
    - Material response – elastic vs. inelastic vs. plastic
  - Response
    - Static, dynamic, blast, impact, contact, buckling, transient, etc.
  - Able to be performed using rather basic PC platforms

FEA



- Possible pitfalls?
  - Model creation and discretization (element #)
    - "Always make it look like the picture"
  - Loads
    - Correctly calculated? Applied? All included?
  - Boundary conditions ("supports")
    - Correctly accounted for? Applied? All included?
  - Material behavior
    - Correctly represented *throughout its anticipated load range*

FEA

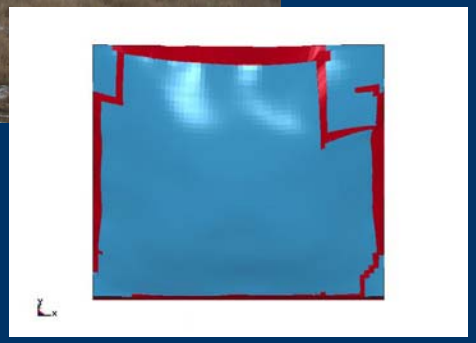
- How become proficient?
  - Practice, practice, practice
  - Understand theory behind FEA method and *how computer forms and solves the problem*
  - Attend workshops and conferences organized by software vendors, professional groups

Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

Background – Innovative Materials

- Drs. Scheetz and Schokker
  - Concrete
- Me
  - Polyurea



Background – Polyurea

- Polyurea – *innovative protective coating system*
  - Introduced by Texaco in 1989
  - Known Advantages vs. Polyurethanes (traditional coatings)
  - Applications
    - DoD – Civil Infrastructure
    - DoD – other apps
      - Army/Navy – Spray on armor (Humvees)
      - Navy – Ship hulls (U.S.S. Cole)
    - Other – Civil Infrastructure
      - Rail cars
      - Water storage tanks
      - Chemical plant infrastructure

Sources:
PCI: http://www.pcimag.com/CDA/Archives/779f754db76a7010VgnVCM10000
DefenseReview.com: http://www.defensereview.com/article502.html,
Polymer Materials for Structural Retrofit, Knox et al., AFRL

Background – Polyurea

- DoD applications – ***Polyurea***
  - AFRL
  - ERDC-WES
  - Army
  - Navy
  - Pentagon
    - Retrofit
- Public domain?

Untreated stud wall

Coated with polyurea

32 DefenseNews April 26, 2004

TechnologyWatch

THIS WEEK

INNOVATIONS IN WARFARE

Polymer Protection

Spray-on Armor: Lighter, Cheaper, Even Stronger Than Steel?

By WILLIAM MATTHEWS

While the U.S. Army urges Humvee makers to speed up production lines and turn out more armor-plated vehicles to send to Iraq, the Navy has discovered that it might be possible to protect existing vehicles with a spray-on polymer armor that's lighter, cheaper, and — maybe — even as tough as steel.

The Office of Naval Research has achieved promising results with spray-on armor applied to Marine Corps Humvees, Rear Adm. Jay Cohen, the chief of naval research, told a House subcommittee in March.

Using photos of Humvees hit by mine blasts, and a section of polymer-coated steel, Cohen demonstrated how the armor sprayed

Source: Polymer Materials for Structural Retrofit, Knox et al., AFRL; Army Times

Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

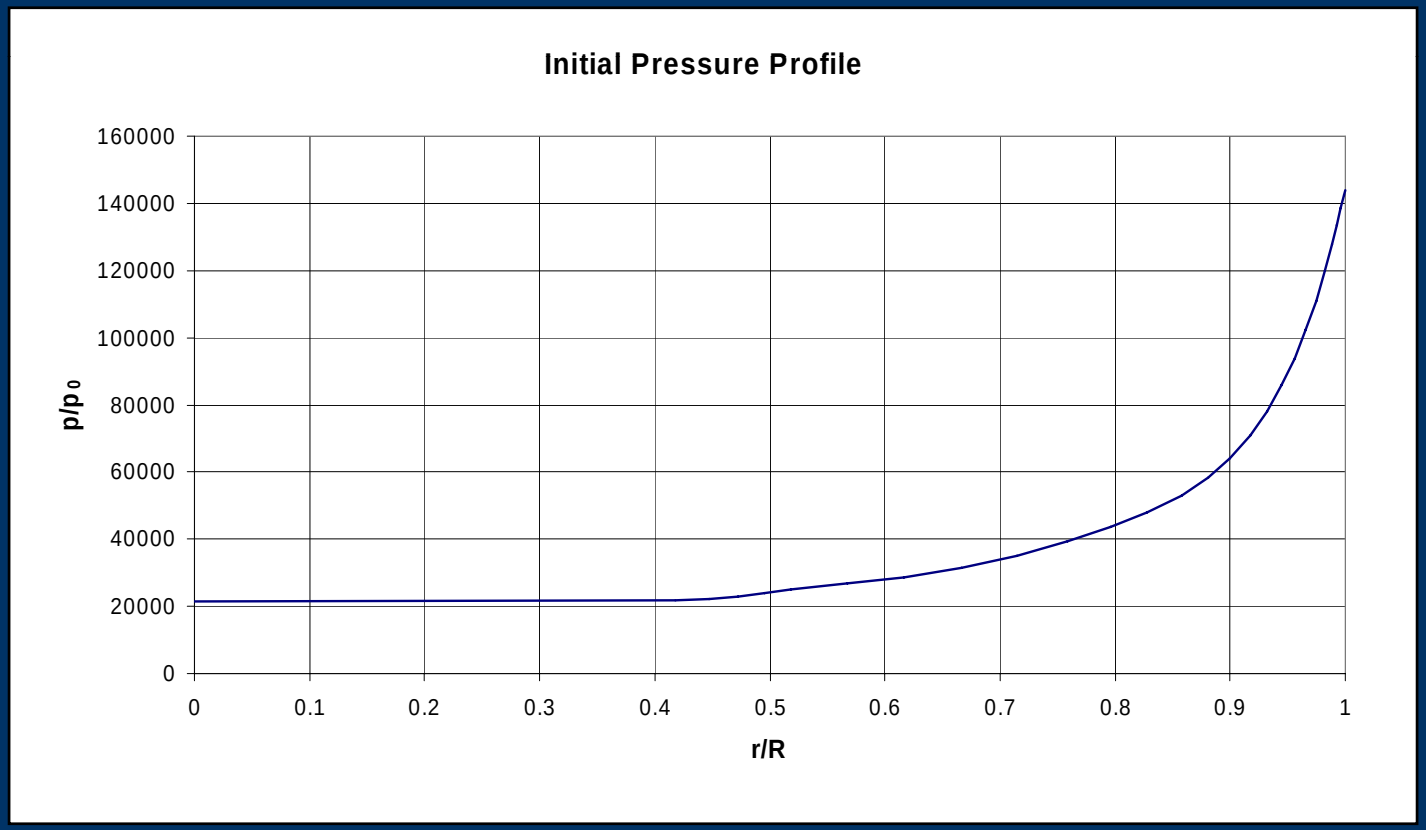
Blast Simulation CFD Method (Long, PSU)

- Unstructured-grid, time-accurate Euler code
- Finite volume, Runge-Kutta time marching
- Code is called PUMA2
- Has been in use at Penn State for many years, thoroughly validated on a wide range of problems

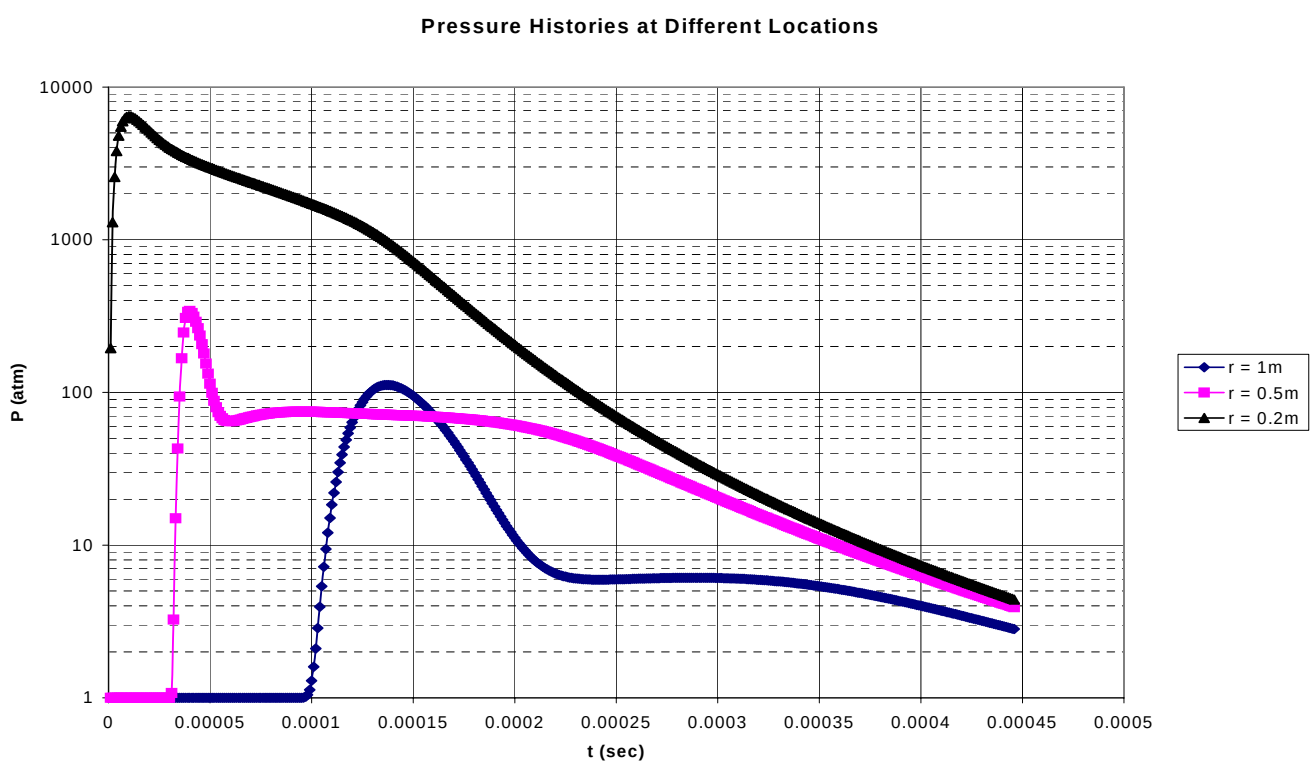
Blast CFD - Assumptions

- 75 lbs. of TNT
- Explosive is spherical in geometry
- Uniform explosion

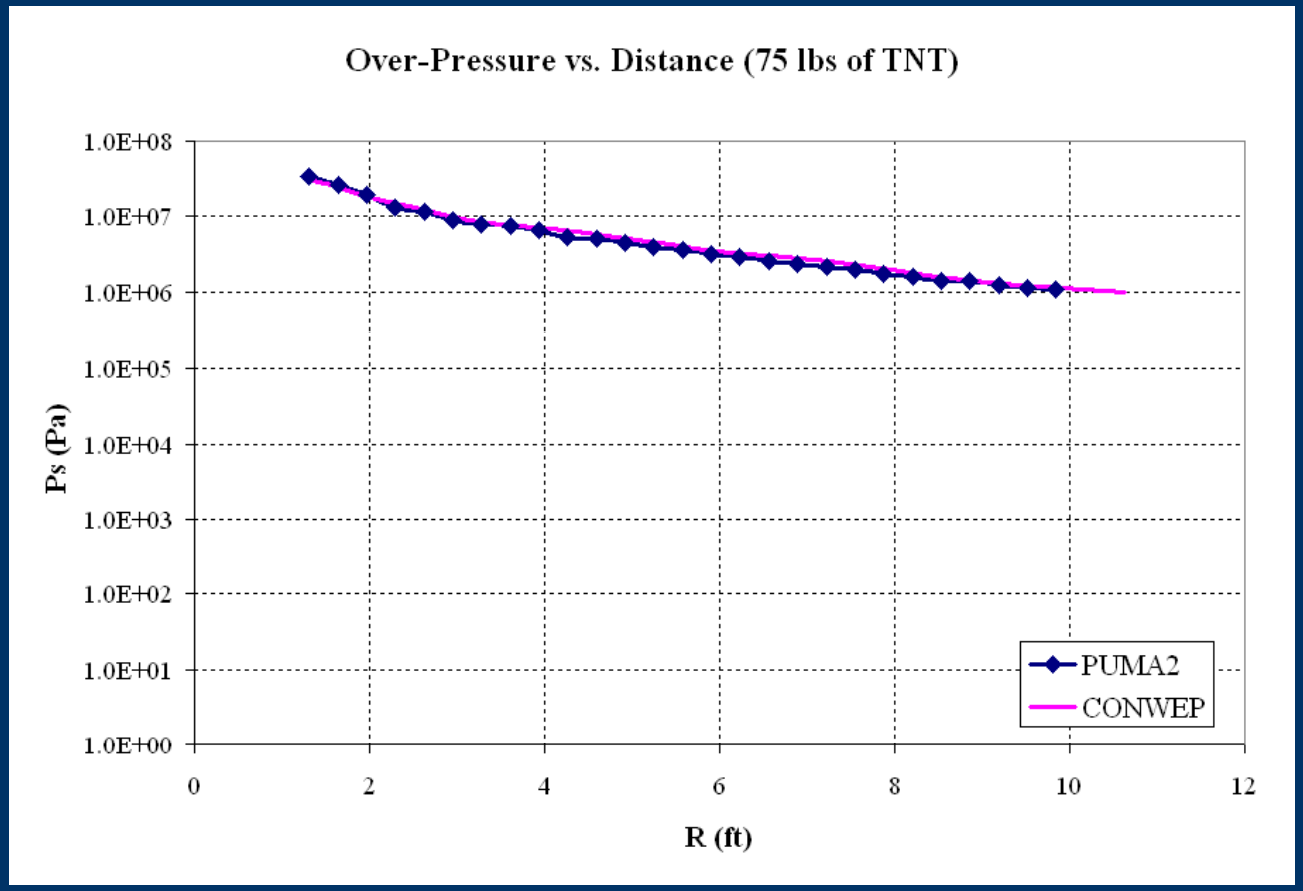
Blast CFD - Initial Pressure Profile



Blast CFD - Pressure History



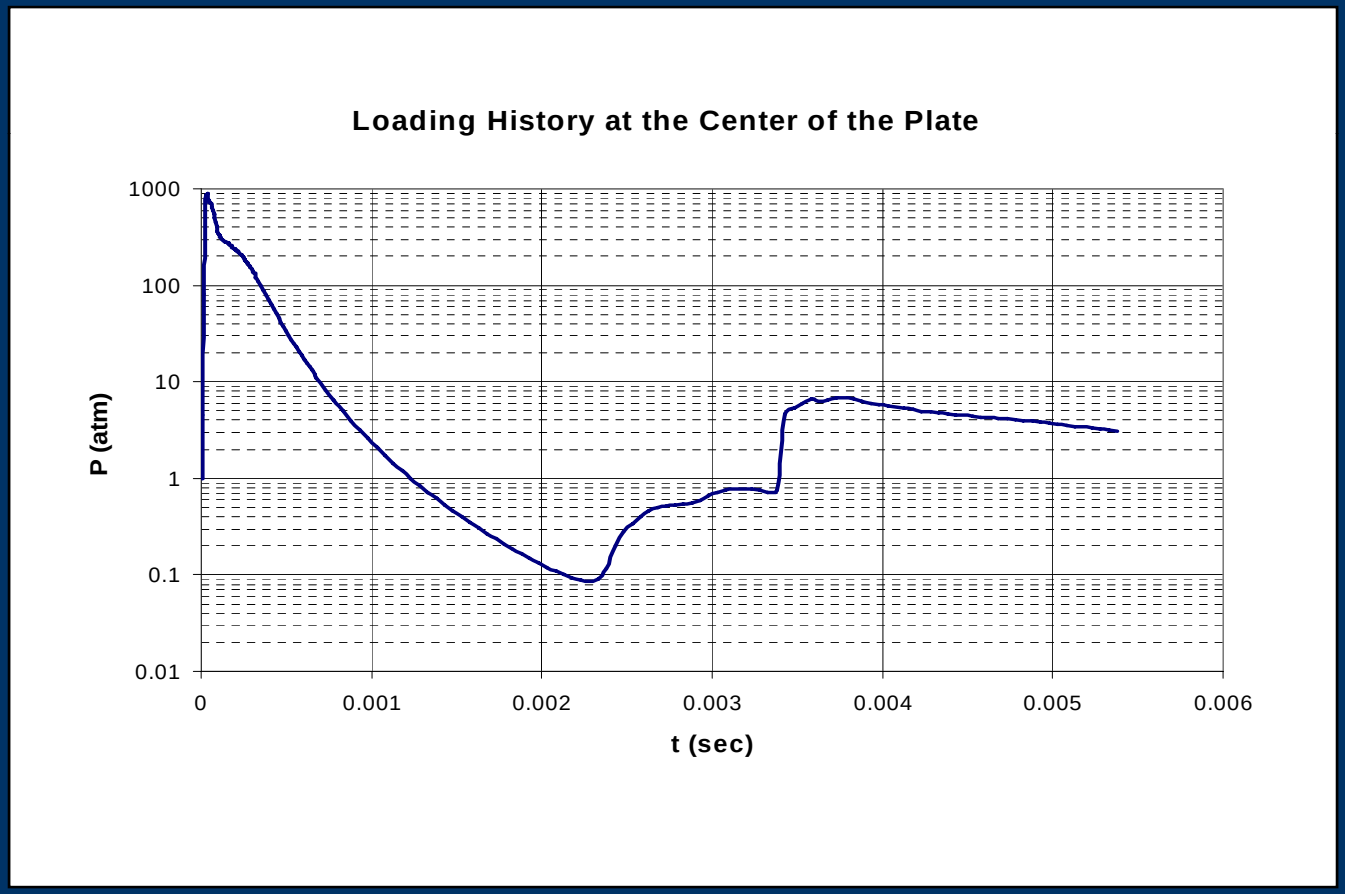
Blast CFD – PUMA2 vs. ConWep



Blast CFD - Simulations w/ Plate

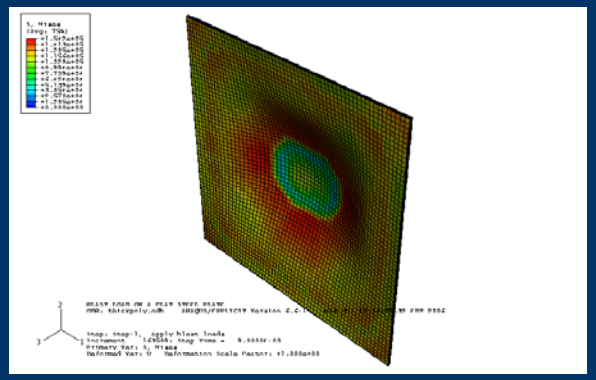
- Plate Dimensions (60in by 60in)
- 75 lbs. of TNT
- Plate located approx 3 ft away from the explosive

Blast CFD - Loading History @ Center



Background – Fluid/structure simulations w/ CFD

- Structure - commercial codes
- Interaction
  - Loosely coupled
- Mechanisms behind protection?
- Parameters to control performance?



Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

Focus Areas – Innovative Concretes

- Numerical fluid/structure program
  - Material models
  - Component representation
  - Response of various components under impact and blast loading

Focus Areas – Innovative Concretes

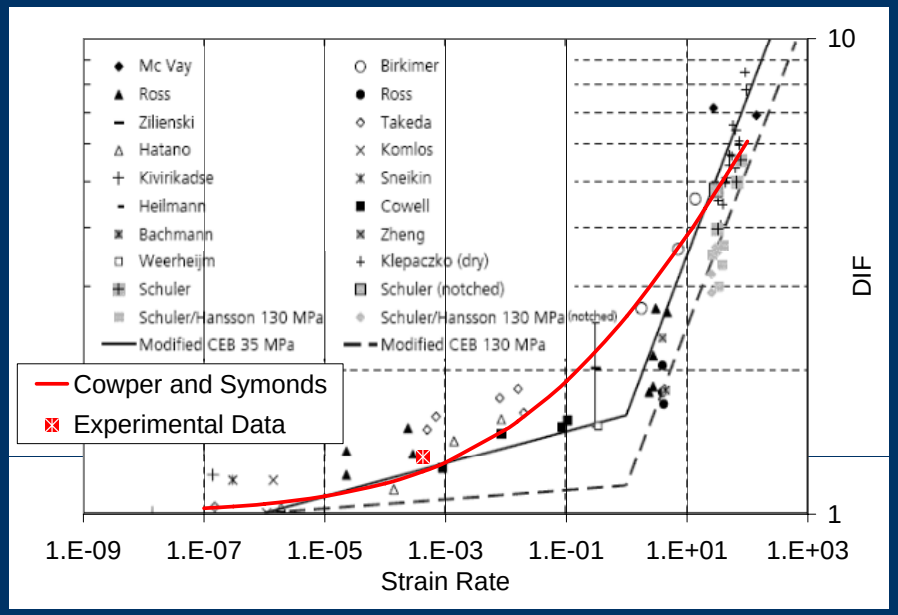
- Numerical fluid/structure program
  - Material models
  - Component representation
  - Response of various components under impact and blast loading

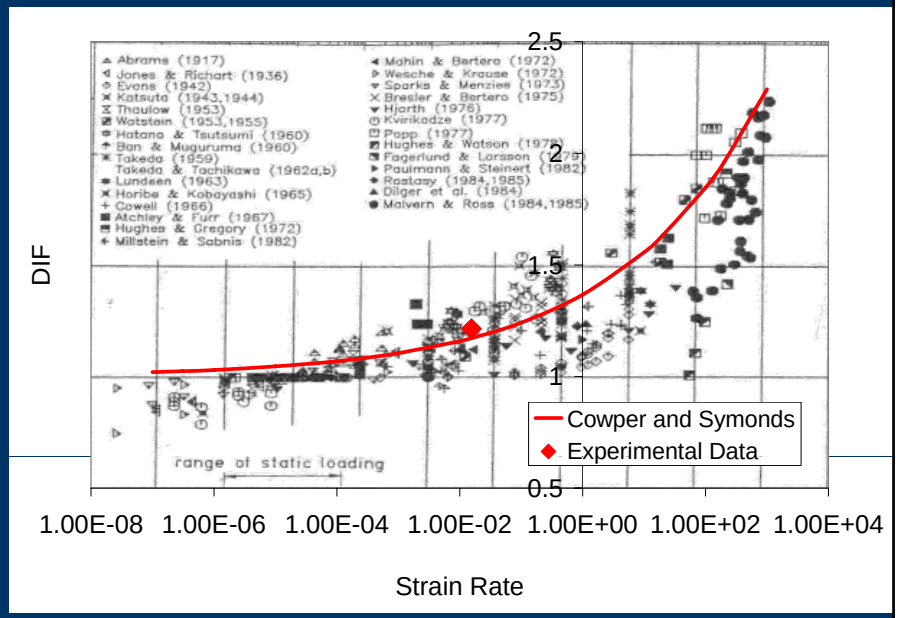
Long Fiber Concrete – Material Model

- Create and validate material model
- Accurately describes behavior of long carbon fiber reinforced concrete
  - Dynamic loads – Impact 1st
  - LS-Dyna

Long Fiber Concrete – Material Model

- **Selected Model – Cowper-Symonds (Tension and Compression)**



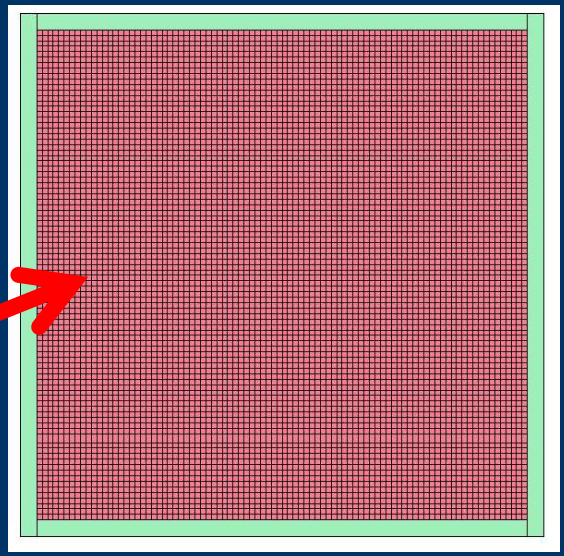


Focus Areas – Innovative Concretes

- Numerical fluid/structure program
  - Material models
  - Component representation
  - Response of various components under impact and blast loading

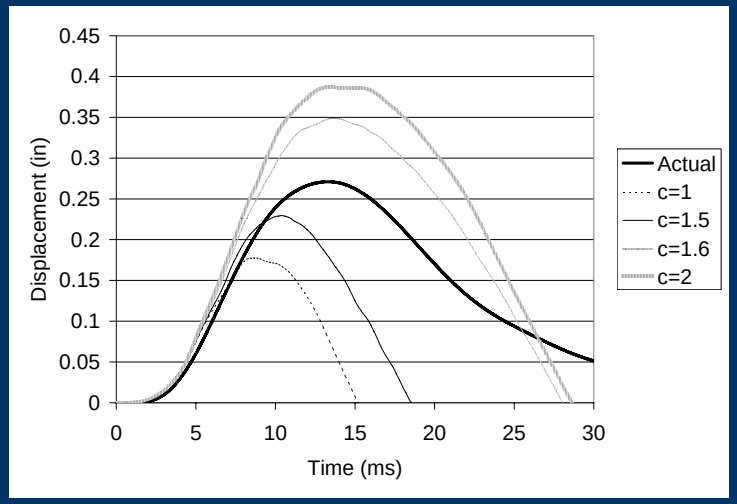
Long Fiber Concrete – Impact

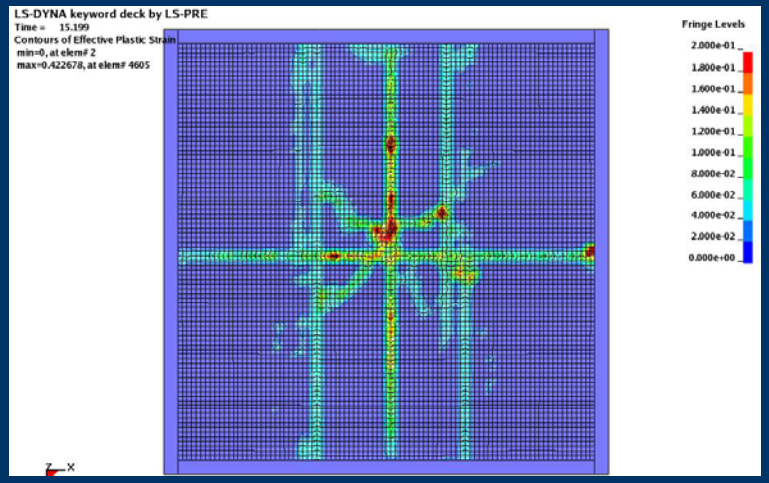
- **Model Instrumented Impact**
  - **Element selection and discretization (element #)**
  - **How represent fibers?**
  - **Boundary conditions**



Long Fiber Concrete – Impact

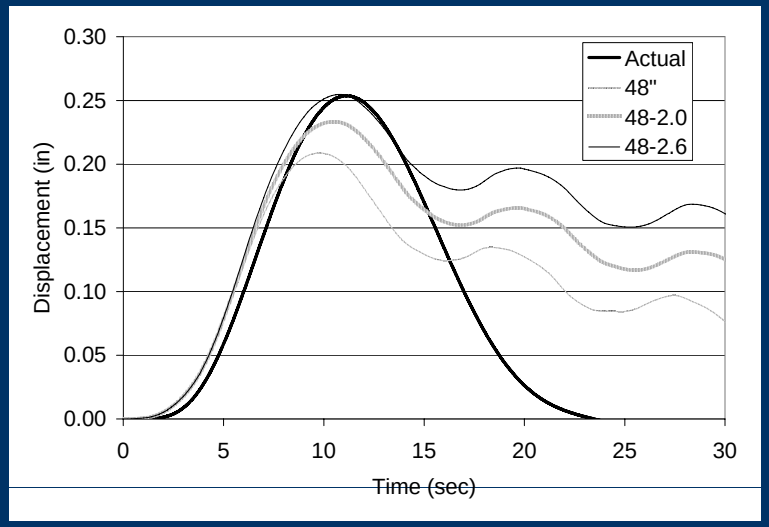
- Model Instrumented Impact
  - How represent fibers? Discrete.
  - Concrete - solids, reinforcement - truss (perfect bond)
  - Rate effects important

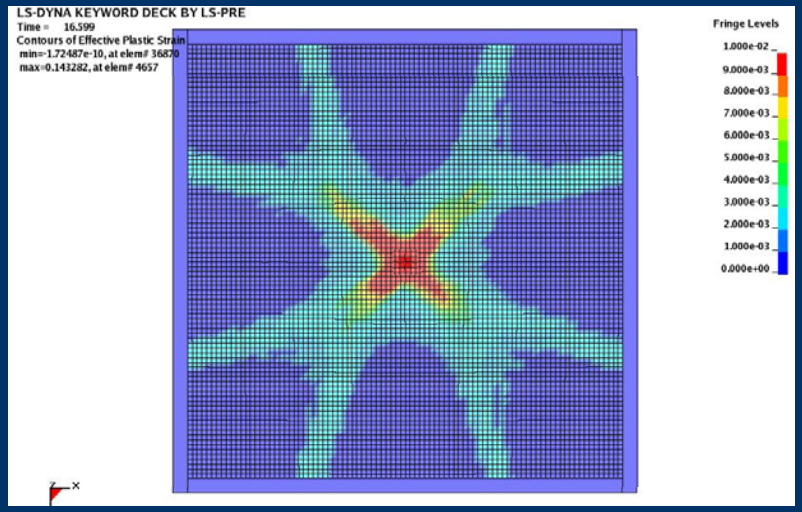




Long Fiber Concrete – Impact

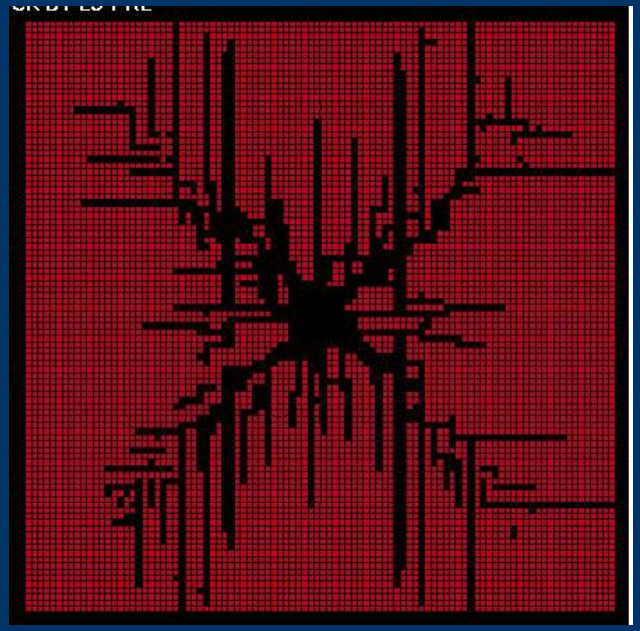
- Model Instrumented Impact
  - How represent fibers? Smeared.
  - Rate effects again important





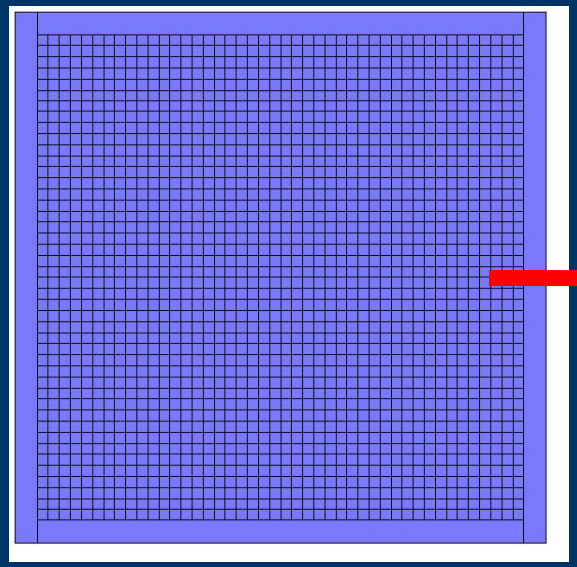
Long Fiber Concrete – Impact

- **Model Instrumented Impact**
  - **How represent fibers? Strain erosion with nonlinear springs.**



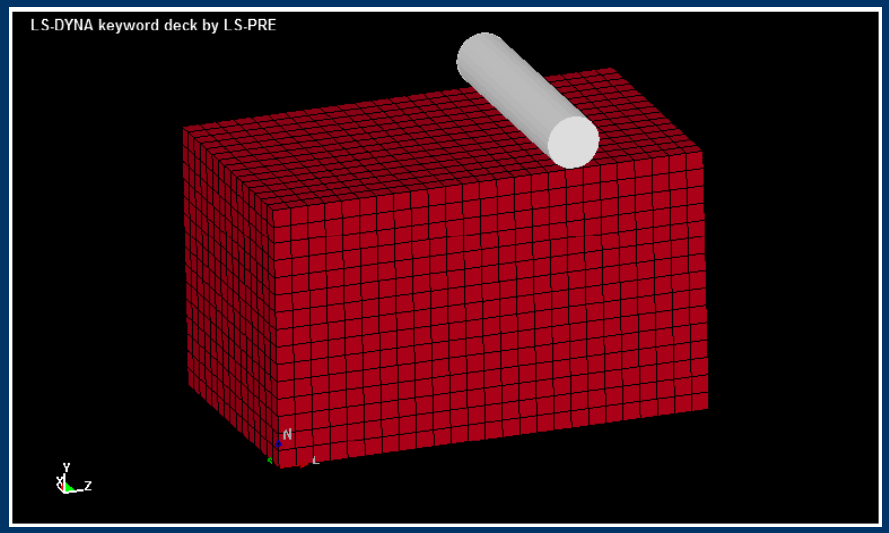
Long Fiber Concrete – Impact

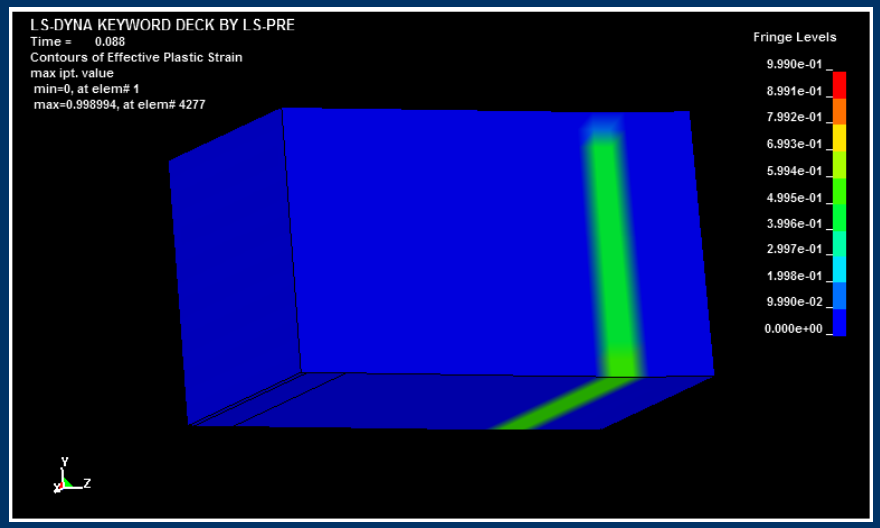
- Model Instrumented Impact – Work for Blast?
  - Controlled by post failure response – 2 selected models NG



Long Fiber Concrete – Blast

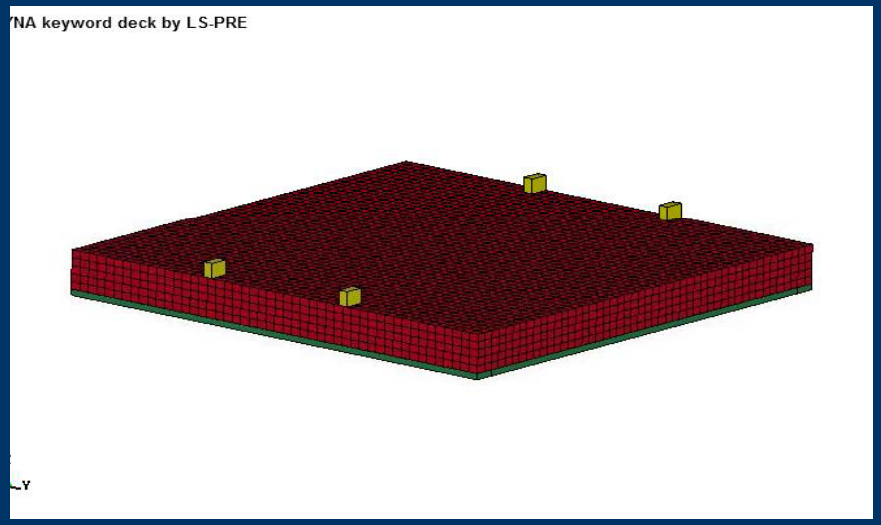
- **Model Blast**
  - **How represent fibers? Tension.**
  - **Available material models in LS-Dyna**
  - **First static, then dynamic**

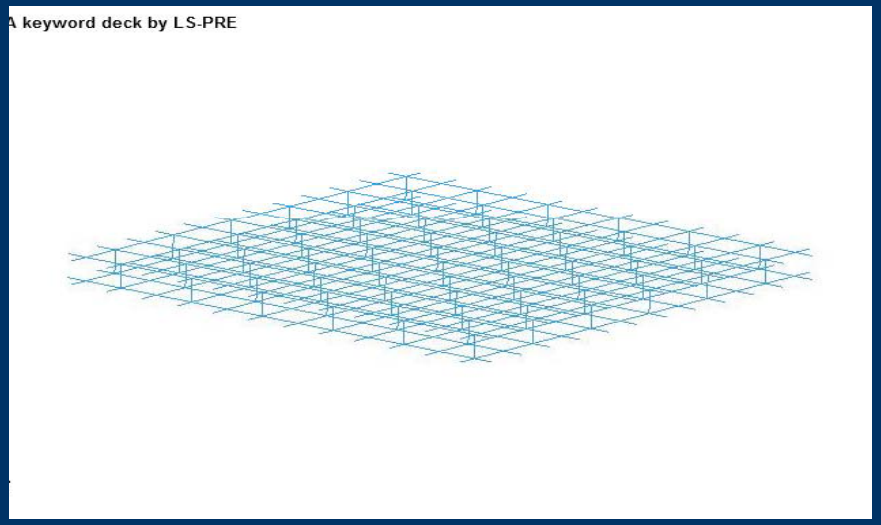




Long Fiber Concrete – Blast

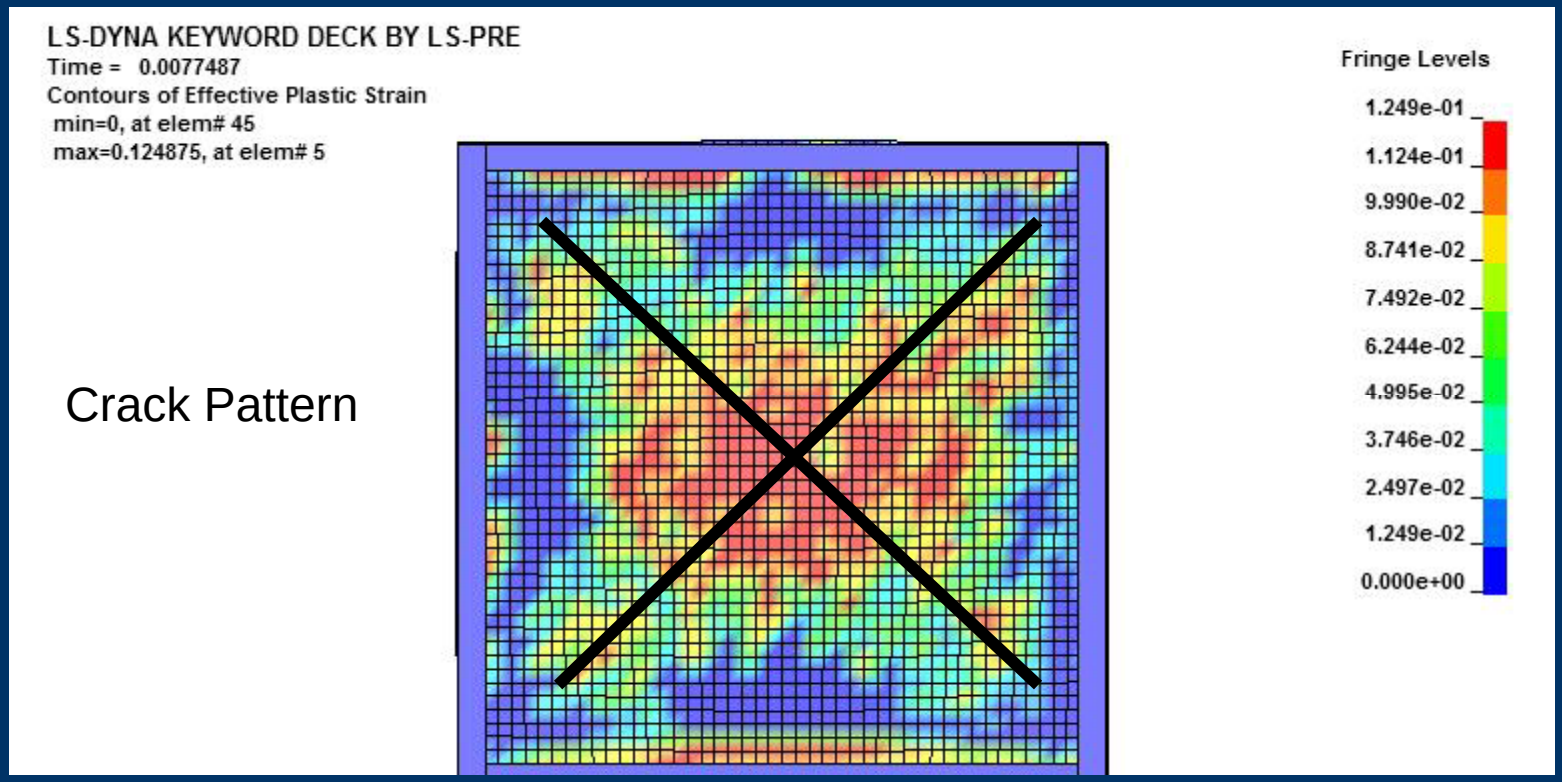
- **Model Blast**
  - **Normally reinforced**





Long Fiber Concrete – Blast

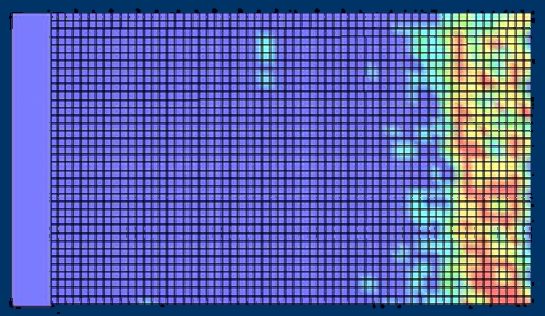
- **Model Blast**
  - **Normally reinforced**



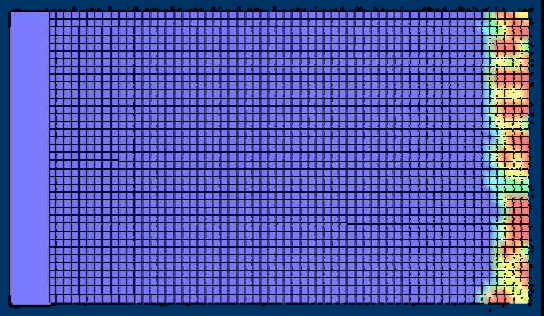
Crack Pattern

Long Fiber Concrete – Blast

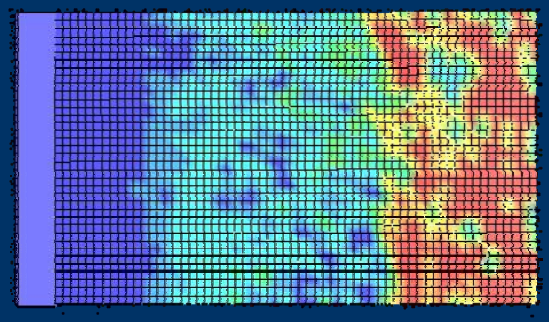
- **Model Blast**
  - **With long fibers**
  - **LS-Dyna Mat'l Model 179**



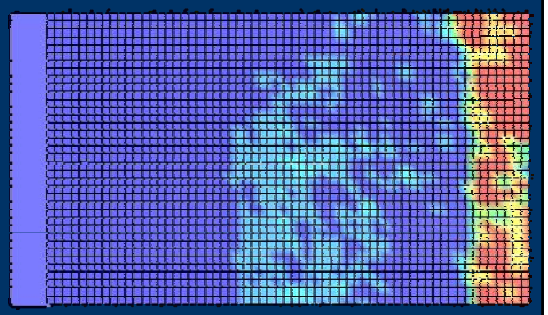
H0



H15



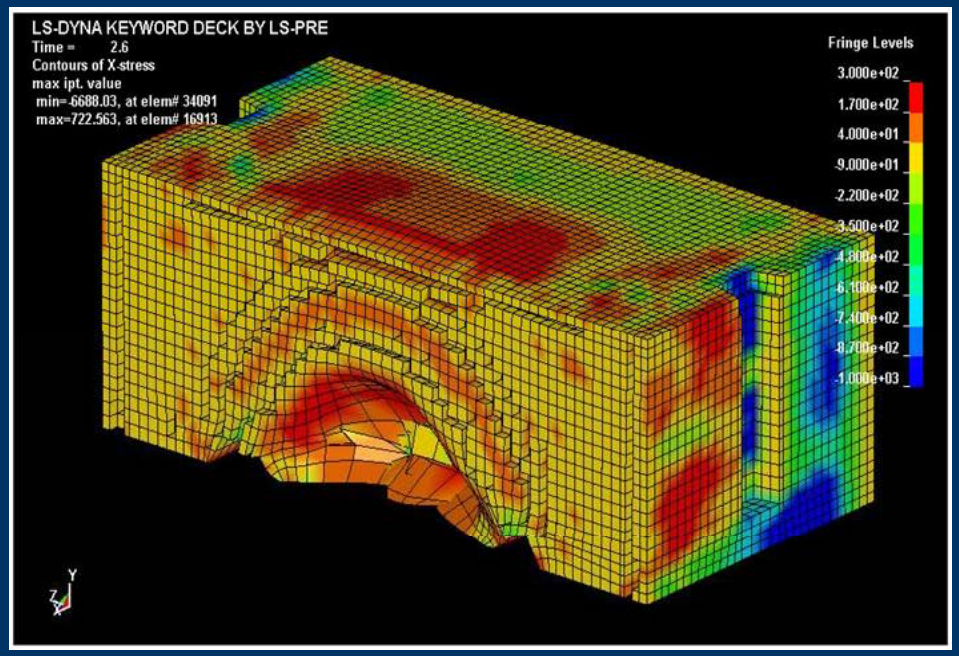
L0



L15

Long Fiber Concrete – Blast

- **Model Blast**
  - **Application – barrier systems**



Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

Focus Areas – Innovative Coatings

- Numerical fluid/structure program
  - Material models
  - Comparison of ABAQUS and LS-DYNA
  - Effect of polyurea on plate under blast loading

Focus Areas – Innovative Coatings

- Numerical fluid/structure program
  - Material models
  - Comparison of ABAQUS and LS-DYNA
  - Effect of polyurea on plate under blast loading

Material model - Polyurea

- Mie-Gruneisen equation of state (Fuentes 2006)
  - **Hydrodynamic material model, F(density, internal energy)**

$$P - P_H = \Gamma \rho (E_m - E_H)$$

$$\Gamma = \Gamma_0 \frac{\rho_0}{\rho}$$

Γ_0: material constant

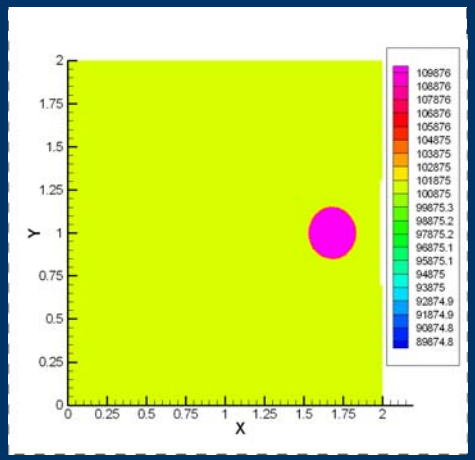
ρ_0 : reference density

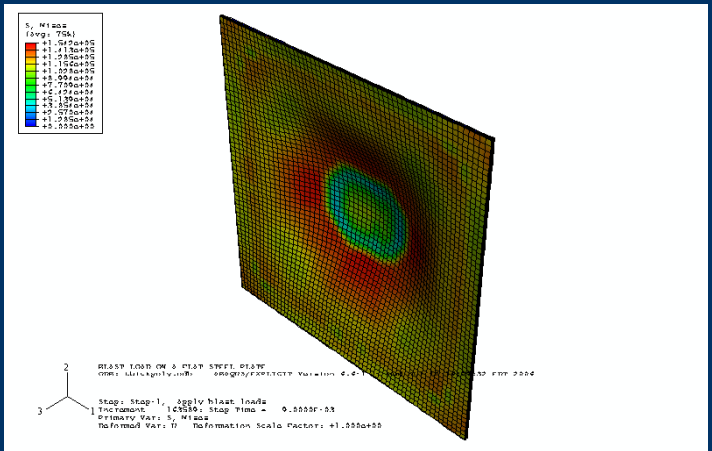
$$E_H = \frac{P_H \eta}{2\rho_0} \qquad \eta = 1 - \frac{\rho_0}{\rho} \qquad P_H = \frac{\rho_0 C_0^{\,2} \eta}{(1 - s\eta)^2}$$

C_0 and s : material constants

Numerical program

- Abaqus - Explicit
- LS-Dyna
- PUMA2

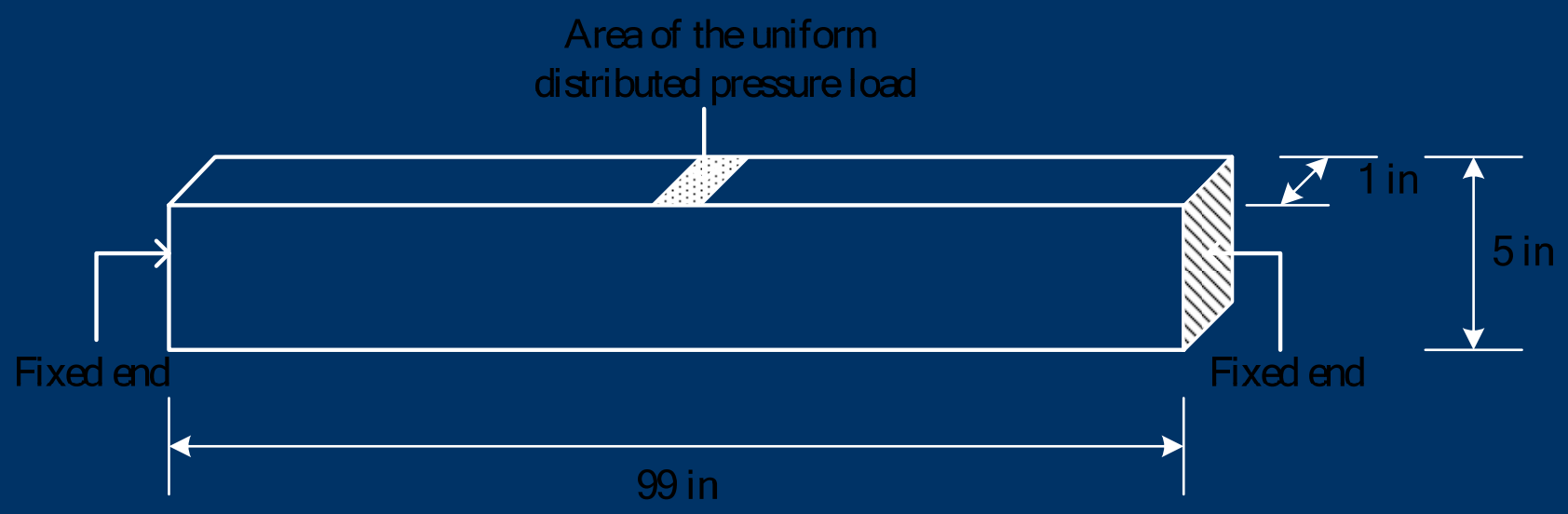




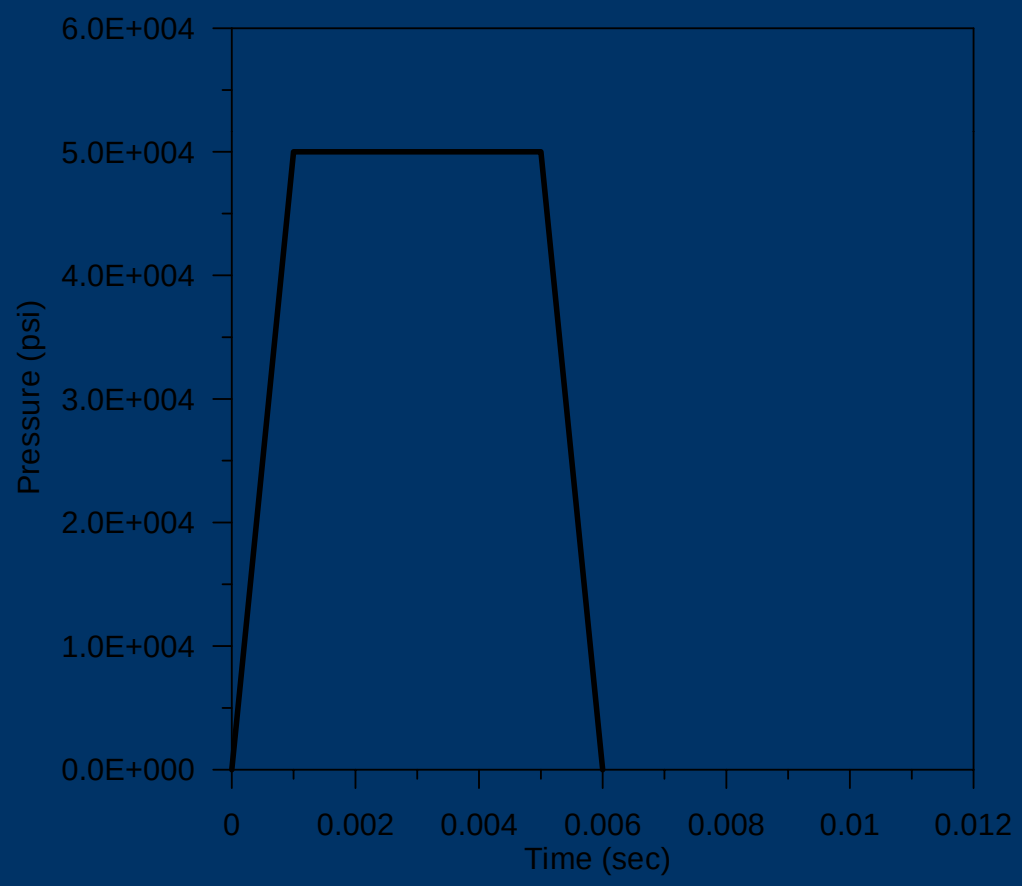
Focus Areas – Innovative Coatings

- Numerical fluid/structure program
  - Material models
  - Comparison of ABAQUS and LS-DYNA
  - Effect of polyurea on plate under blast loading

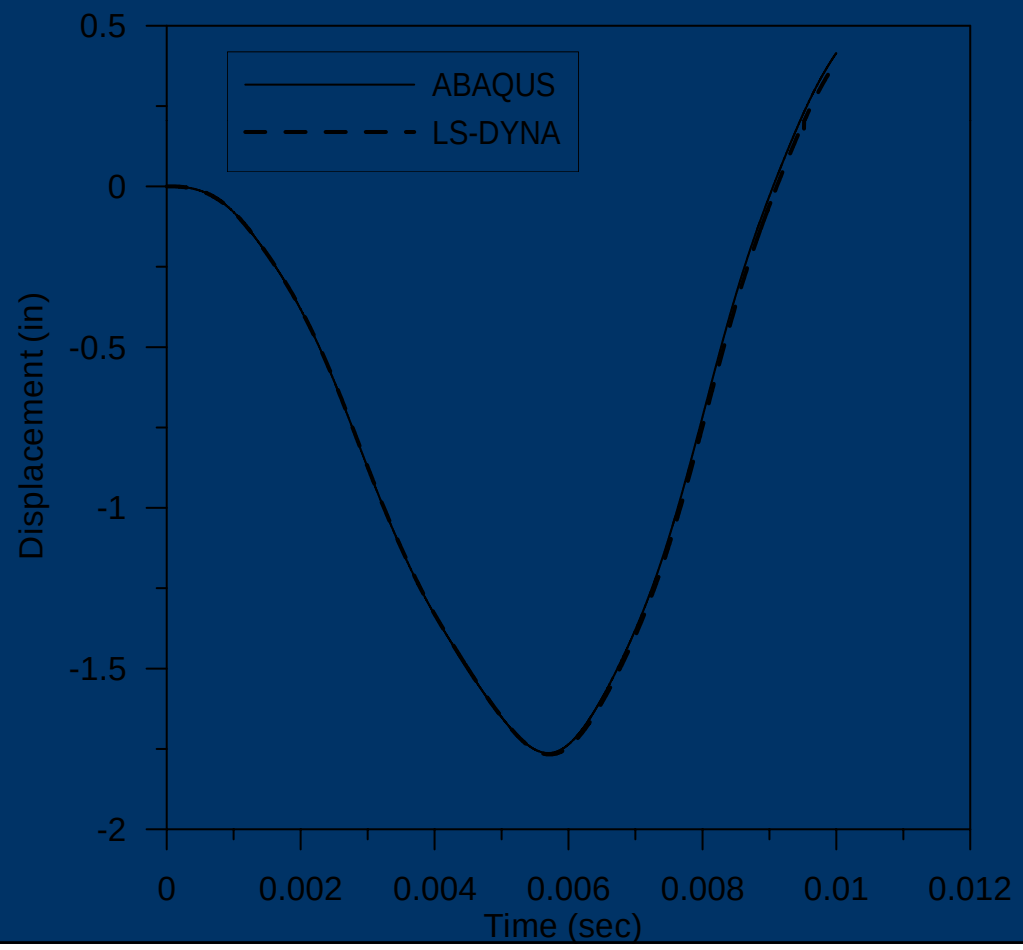
Numerical analysis- ABAQUS and LS-DYNA



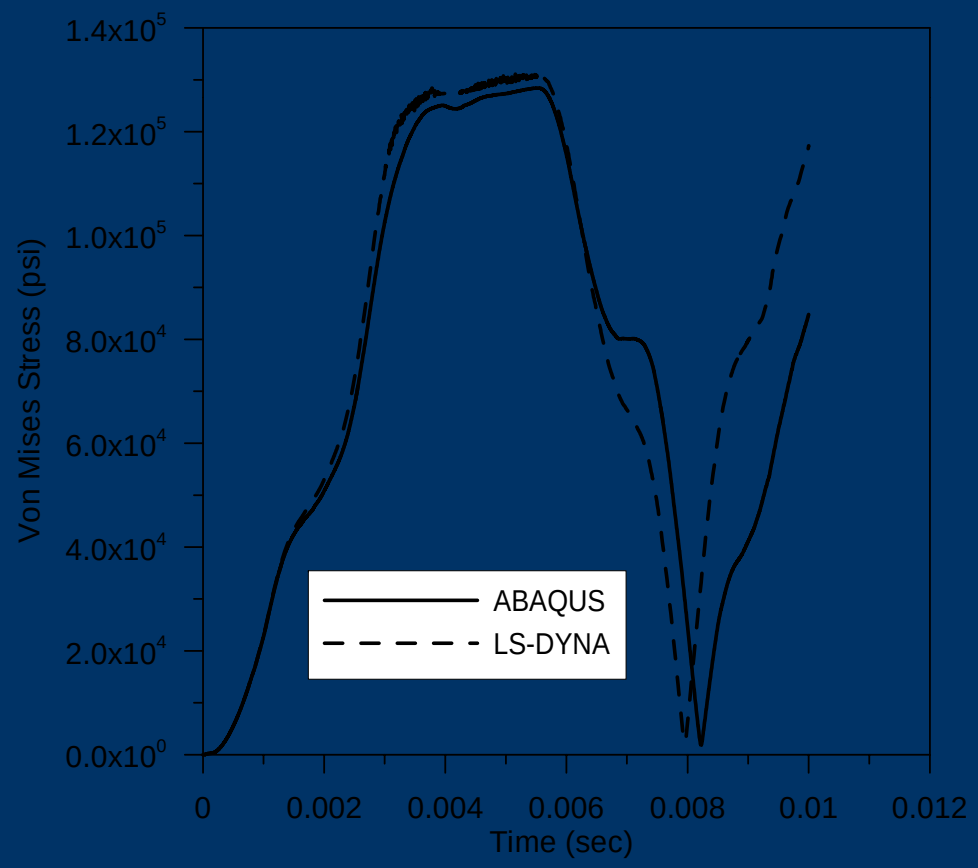
Pressure time-history



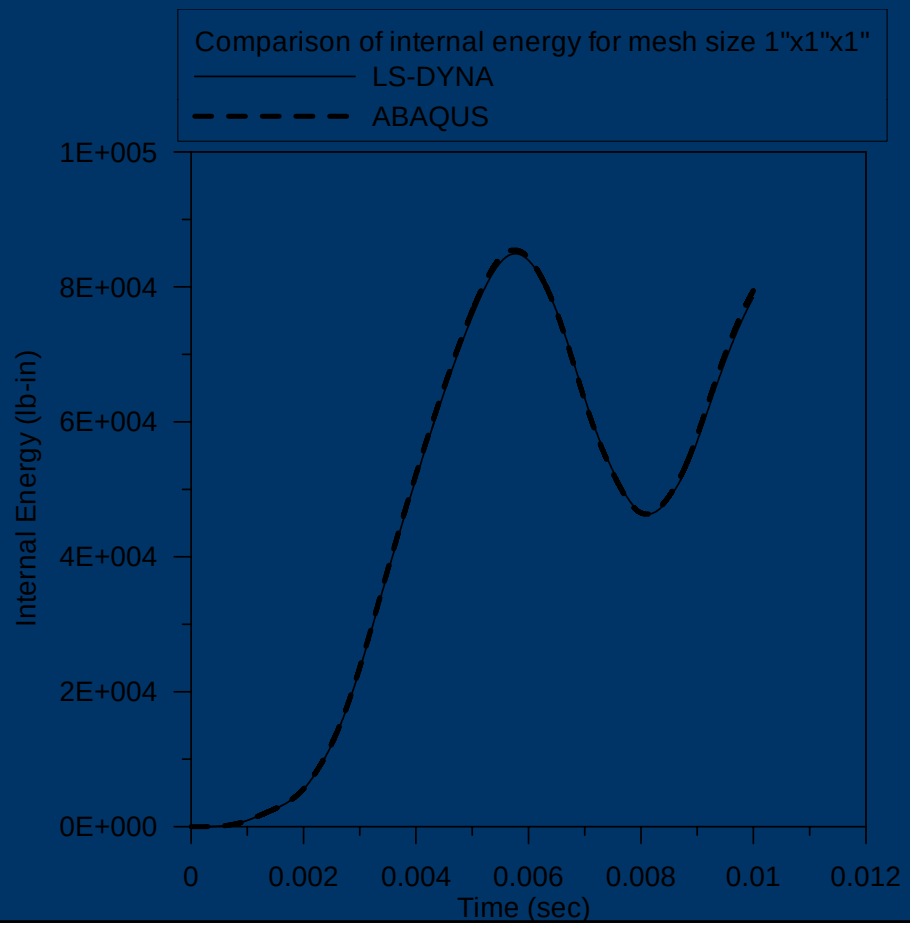
Displacement



Von Mises Stress



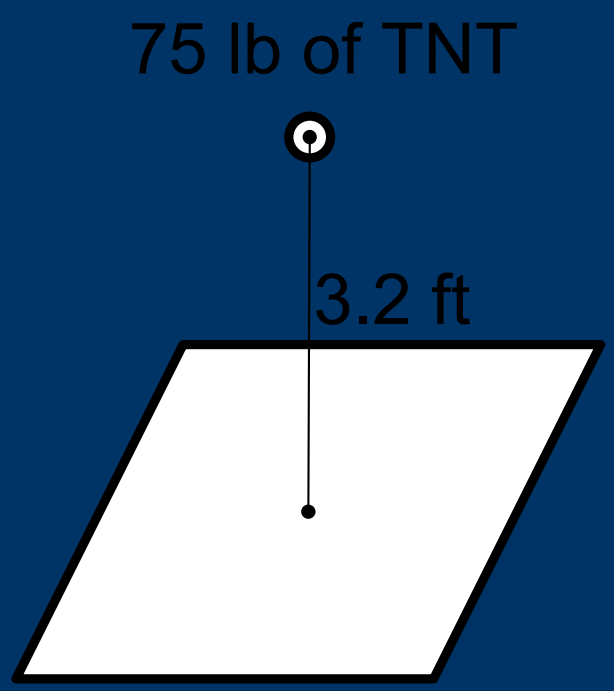
Internal energy



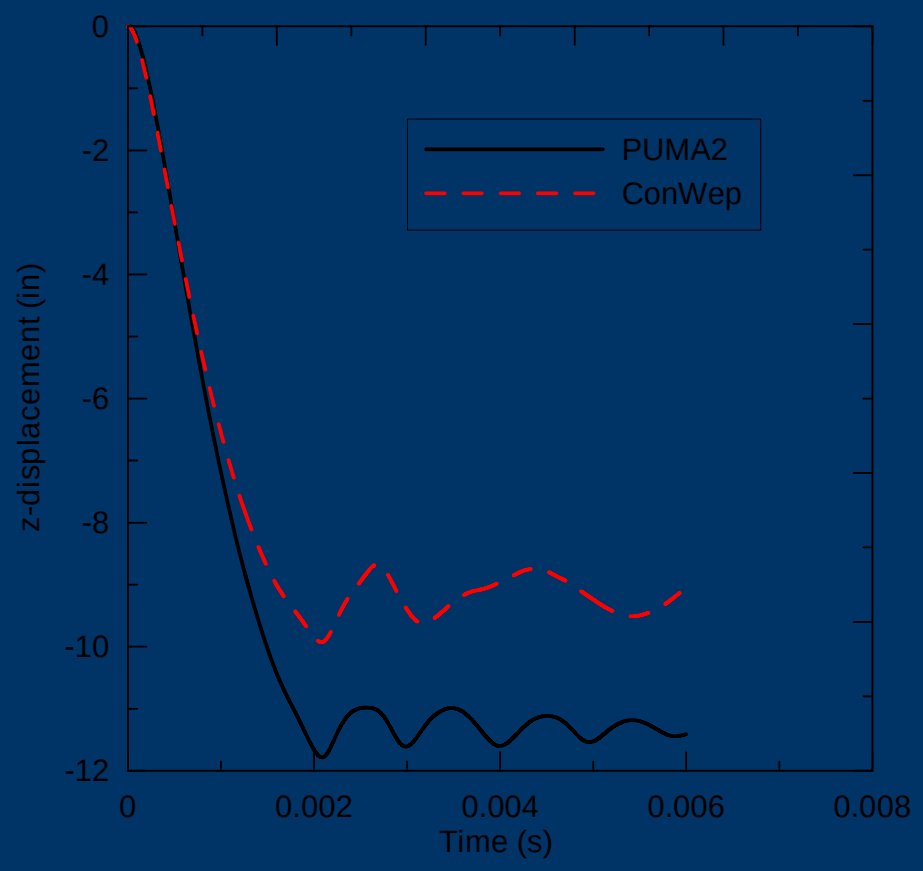
Focus Areas – Innovative Coatings

- Numerical fluid/structure program
  - Material models
  - Comparison of ABAQUS and LS-DYNA
  - Effect of polyurea on plate under blast loading

Configuration of the model

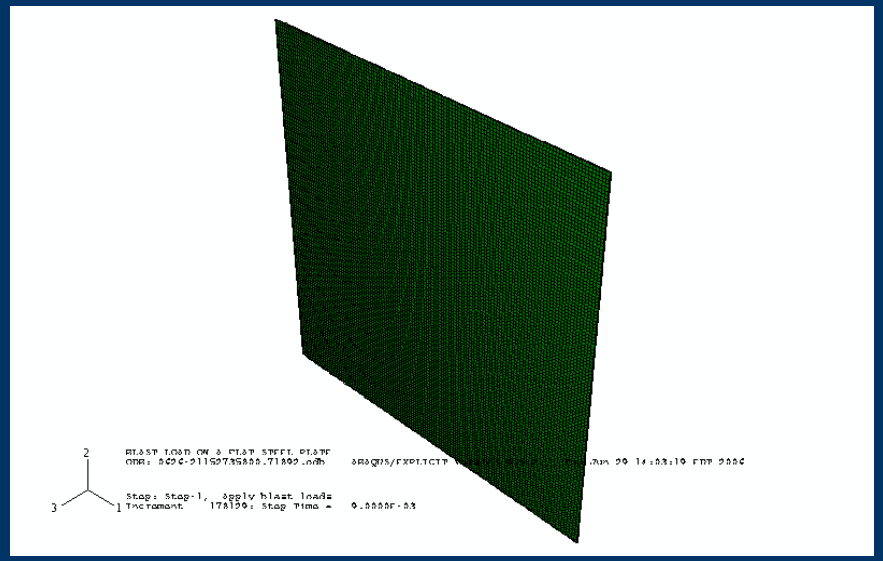


Comparison of displacements



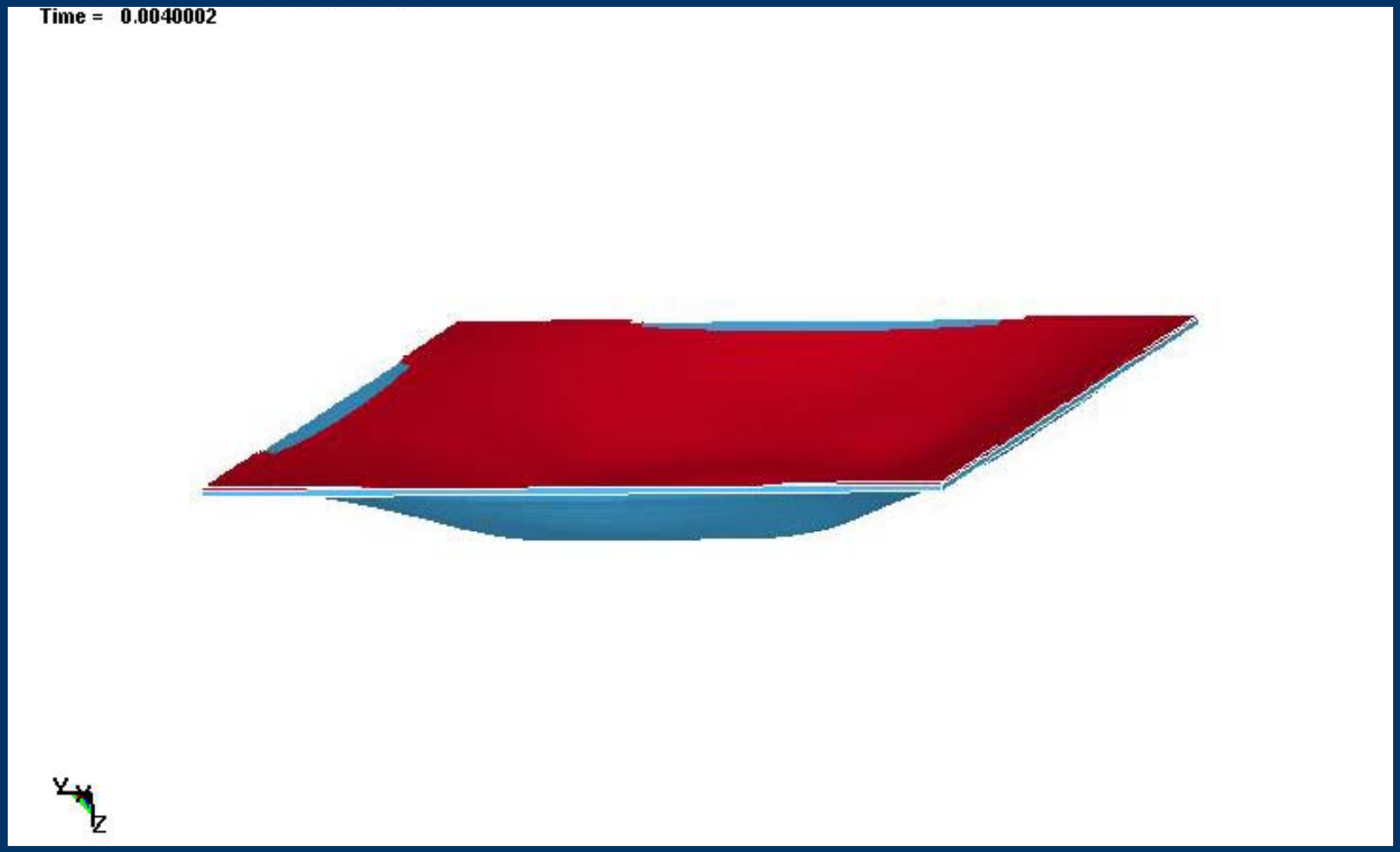
Effect of polyurea on plate under blast loading

- Thickness of coating: 0”, 0.25”, 0.5”
- Polyurea (Air Products)
  - Mie-Gruneisen Equation of State
- Load: PUMA2 CFD code



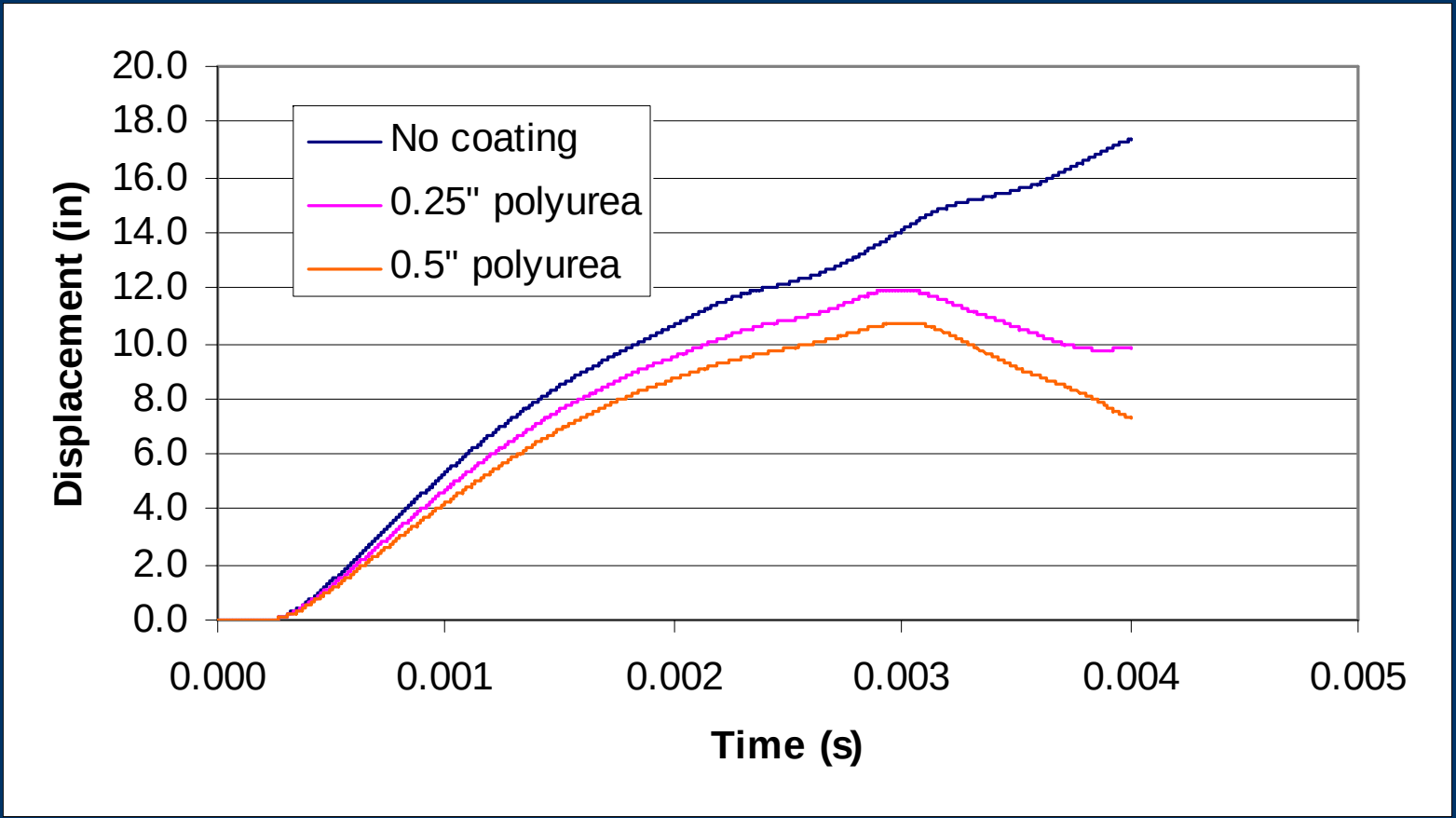
t = 0”

t = 0.25”

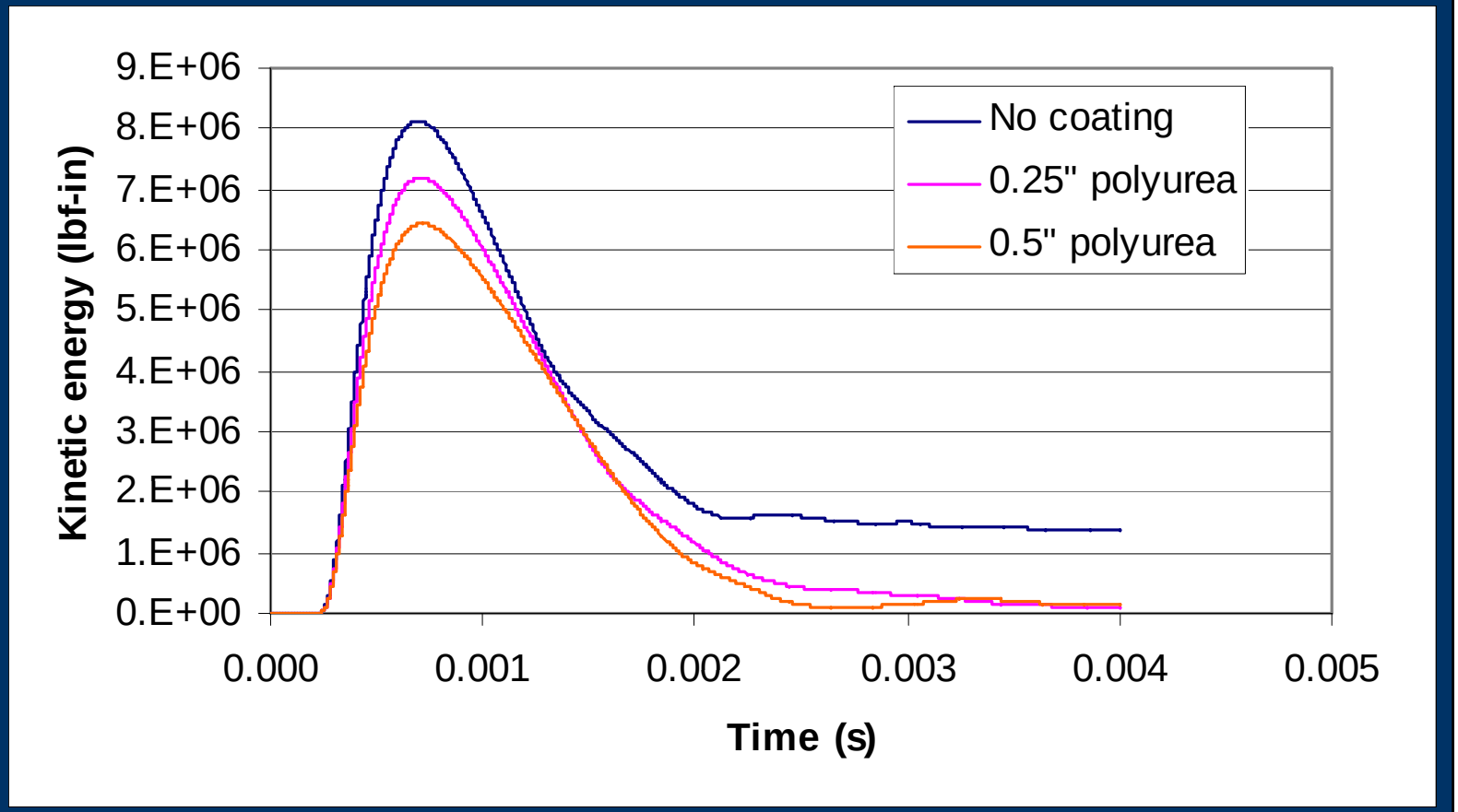


t = 0.5”

Deflection at the center



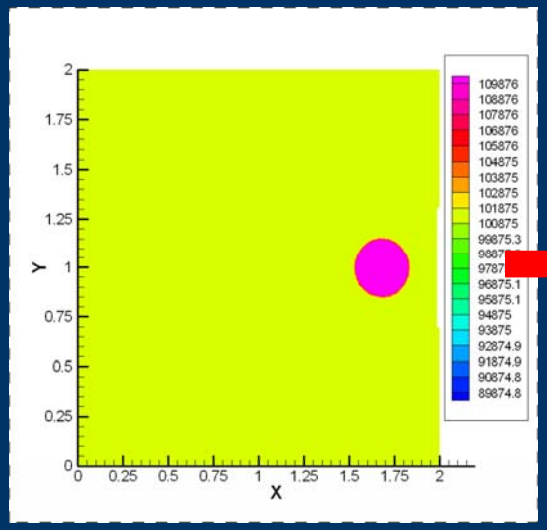
Kinetic energy

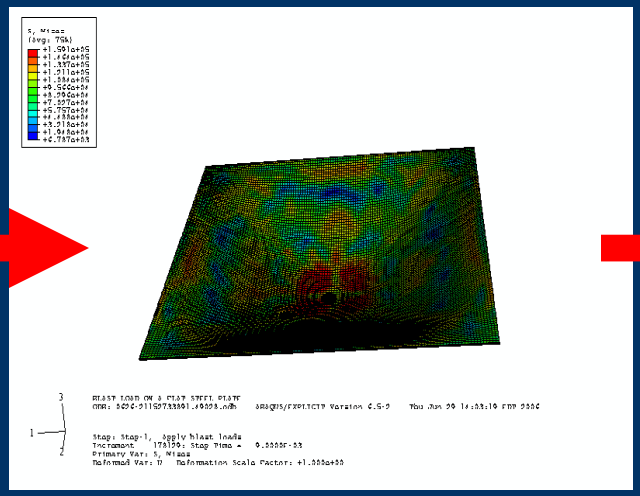


Objectives - COMPUTATIONAL

- Background – Finite Element Analysis
- Background – Innovative Materials (Polyurea)
- Background – CFD Simulations
- Examination of innovative concretes under simulated blast loads – long fiber concrete
- Coating materials to help make structures blast/impact resistant - polyurea

Summary


Y
X
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
109876
108876
107876
106876
105876
104875
103875
102875
101875
100875
99875.3
96875.1
95875.1
94875
93875
92874.9
91874.9
90874.8
89874.8



Questions?

Contact Info

- Daniel Linzell
  - DLinzell@engr.psu.edu