BLIND BLAST SIMULATION
SIMPLE INPUT CONCRETE MODELING

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BLIND PREDICTIONS

A tale of woe …

- I have seen and participate in several of these multiple participant *validation* efforts
- Most *fail* at the critical step of the modelers learning from their mistakes and those of others.
- In the end, it is not how well a model did in THIS effort, but how well a *modeler* will predict an event for which there is no experimental result.

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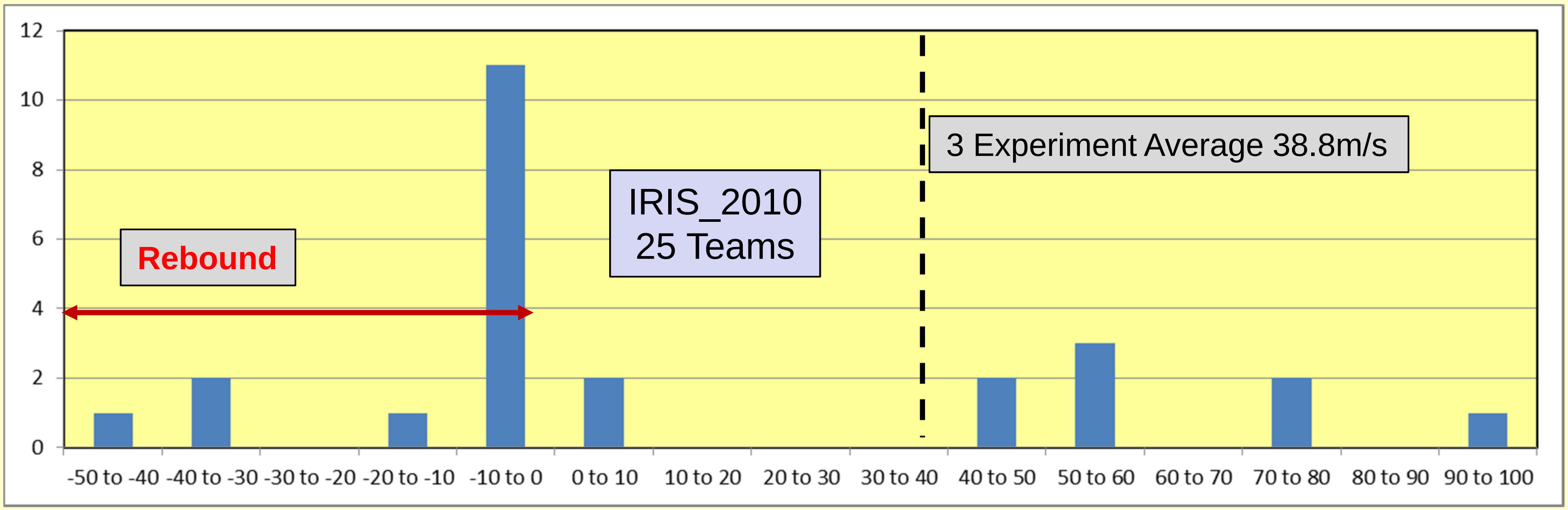
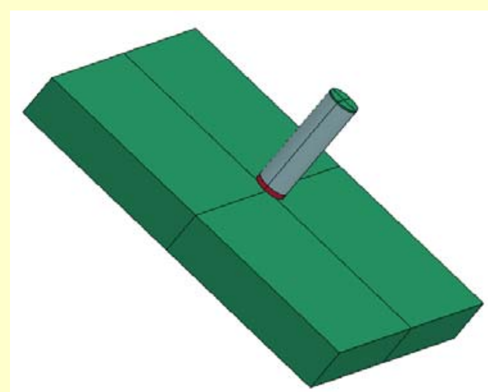
BLIND PREDICTION

Concrete slab perforation: *prediction* of projectile exit speed.

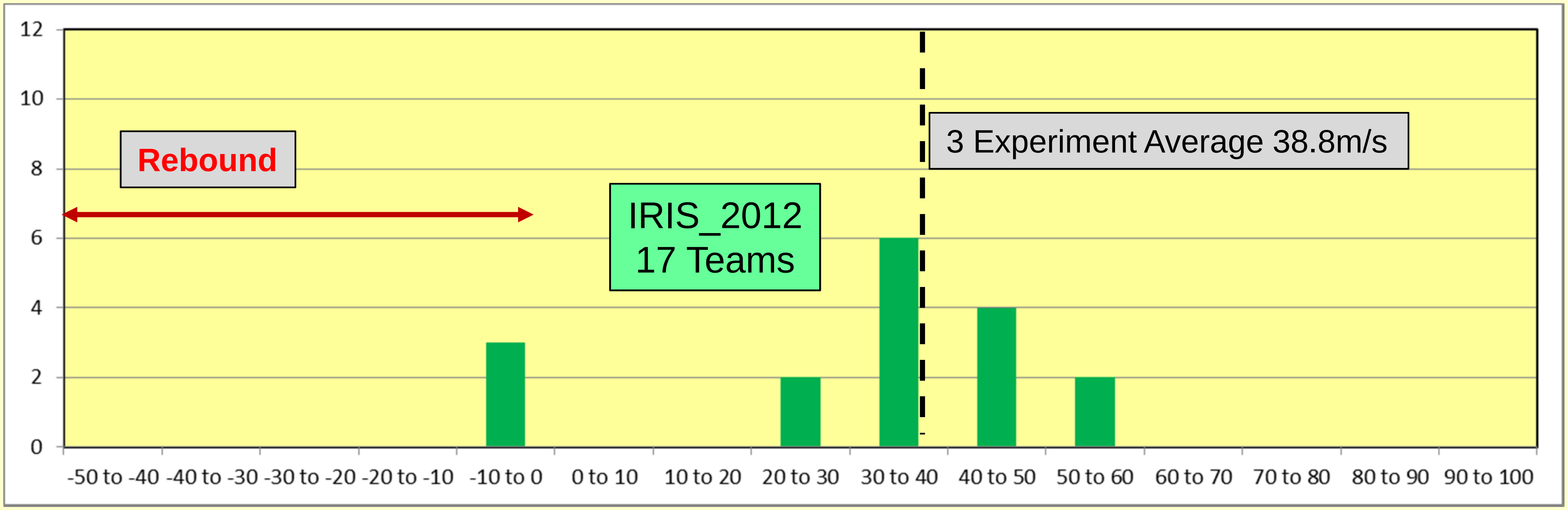


Average	13.07 m/s
CoefVar	**2.80**



POST-DICTION

Concrete slab perforation: *post-diction* of projectile exit speed.



Before	
Average	13.07 m/s
CoefVar	2.80

After	
Average	30.47 m/s
CoefVar	0.60

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PRESENTATION OUTLINE

- Description of the ‘Contest’ and Experiments
- Material Characterization and Simple Input Models
- Model Predicted Deformations
- Comparisons of Experiment and Model Results
- What was learned?

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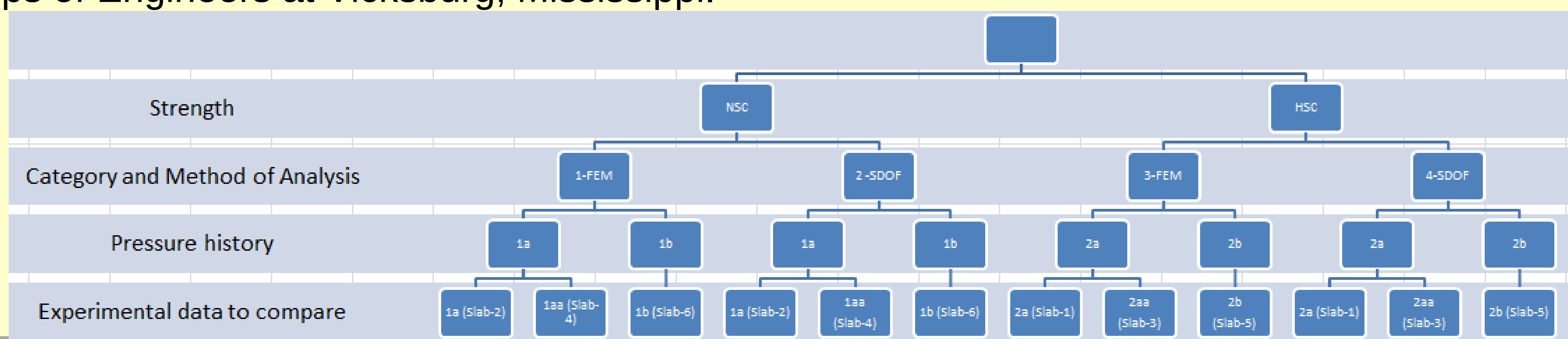
Recently National Science Foundation (NSF) funded a study by University of Missouri Kansas City (UMKC) to perform a batch of blast resistance tests on reinforced concrete slabs (Award # CMMI 0748085, PI: Ganesh Thiagarajan). Based on these results, a Blast Blind Simulation Contest is being sponsored in collaboration with American Concrete Institute (ACI) Committees 447 (Finite Element of Reinforced Concrete Structures) and 370 (Blast and Impact Load Effects), and UMKC School of Computing and Engineering.

The goal of the contest is to predict, using simulation methods, the response of reinforced concrete slabs subjected to a blast load. The blast response was simulated using a Shock Tube (Blast Loading Simulator) located at the Engineering Research and Design Center, U.S. Army Corps of Engineers at Vicksburg, Mississippi.



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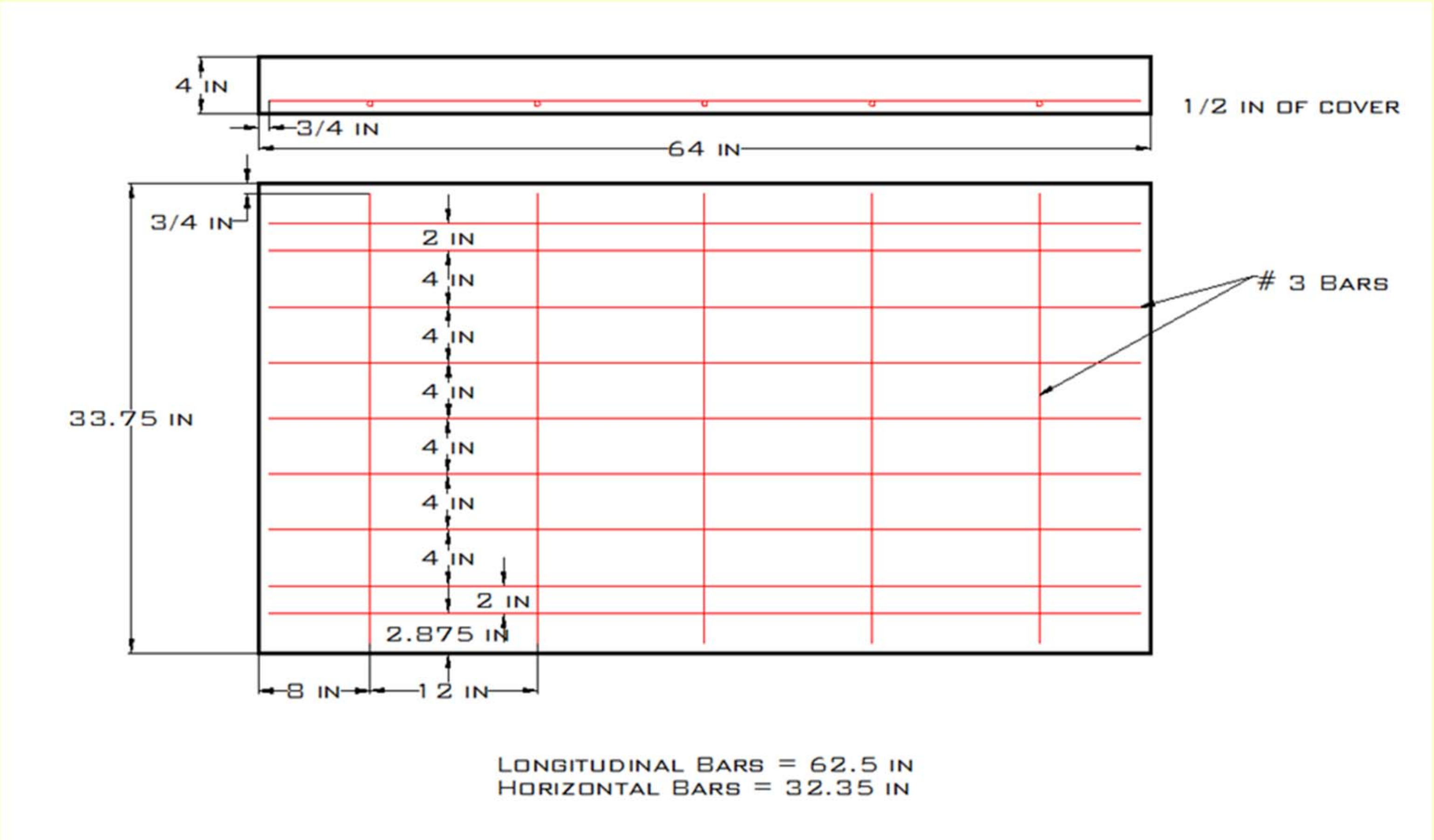
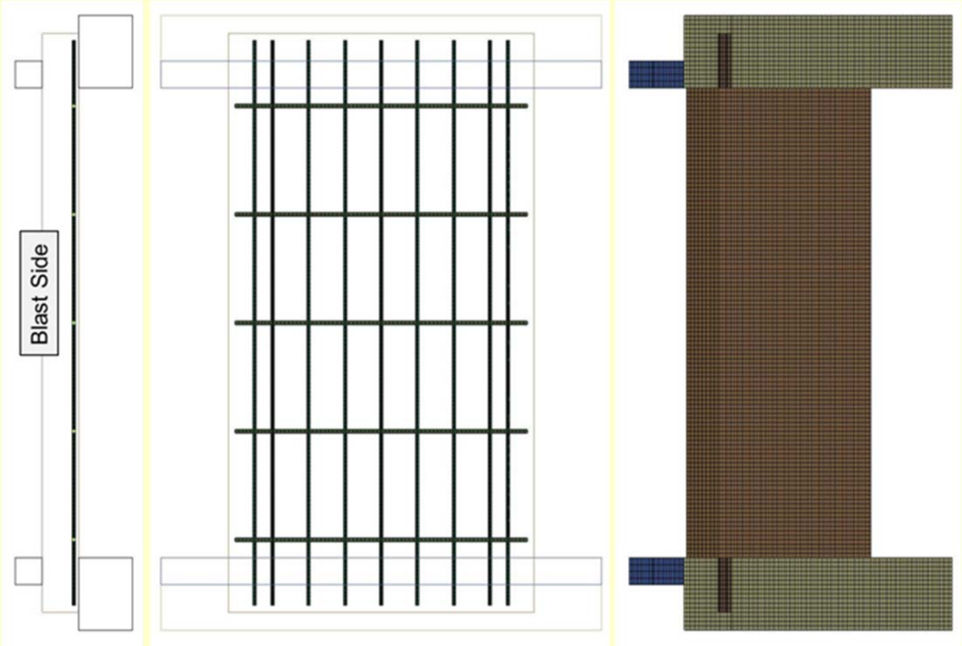
July 2012 to October 2013 http://sce.umkc.edu/blast-prediction-contest/

PROBLEM DEFINITION



Low strength concrete **5ksi (34.5MPa)** with
Number 3 Grade 60 reinforcement 68 ksi (469 MPa).

FIXTURE & MODELING



After some preliminary modeling and assessment, it was decided to use an element size in the concrete slab of **0.5 inches (12.7mm),** which provided for one solid element between the reinforcement and the surface of the slab. This element size corresponds to **8 elements through the thickness of the slab**.

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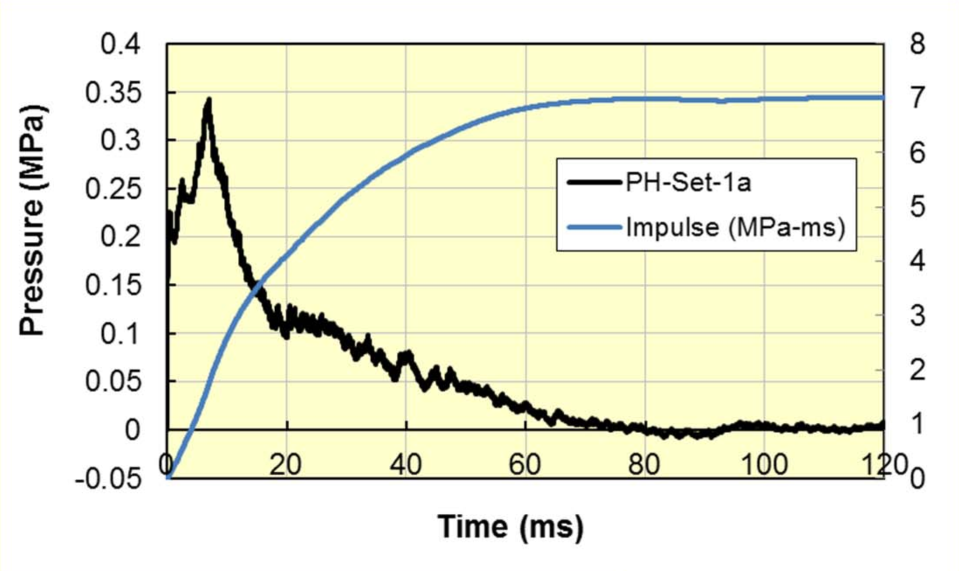
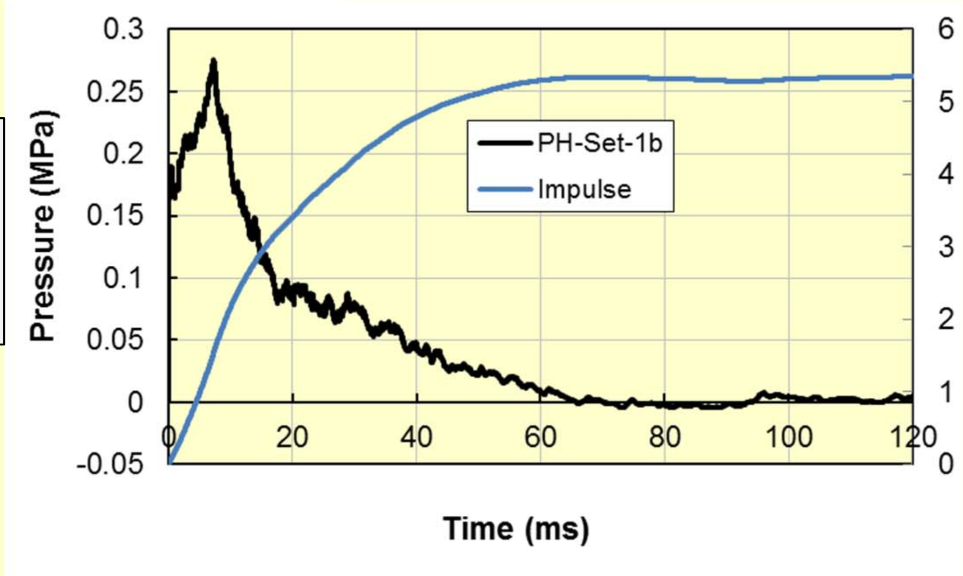
BLAST LOADS



PH-Set-1a - Maximum pressure is 0.34 MPa with a maximum impulse of 7.04 MPa-ms occurring at about 80ms.



PH-Set-1b, the maximum pressure is 0.28 MPa with a maximum impulse of 5.38 MPa-ms occurring at about 60 ms

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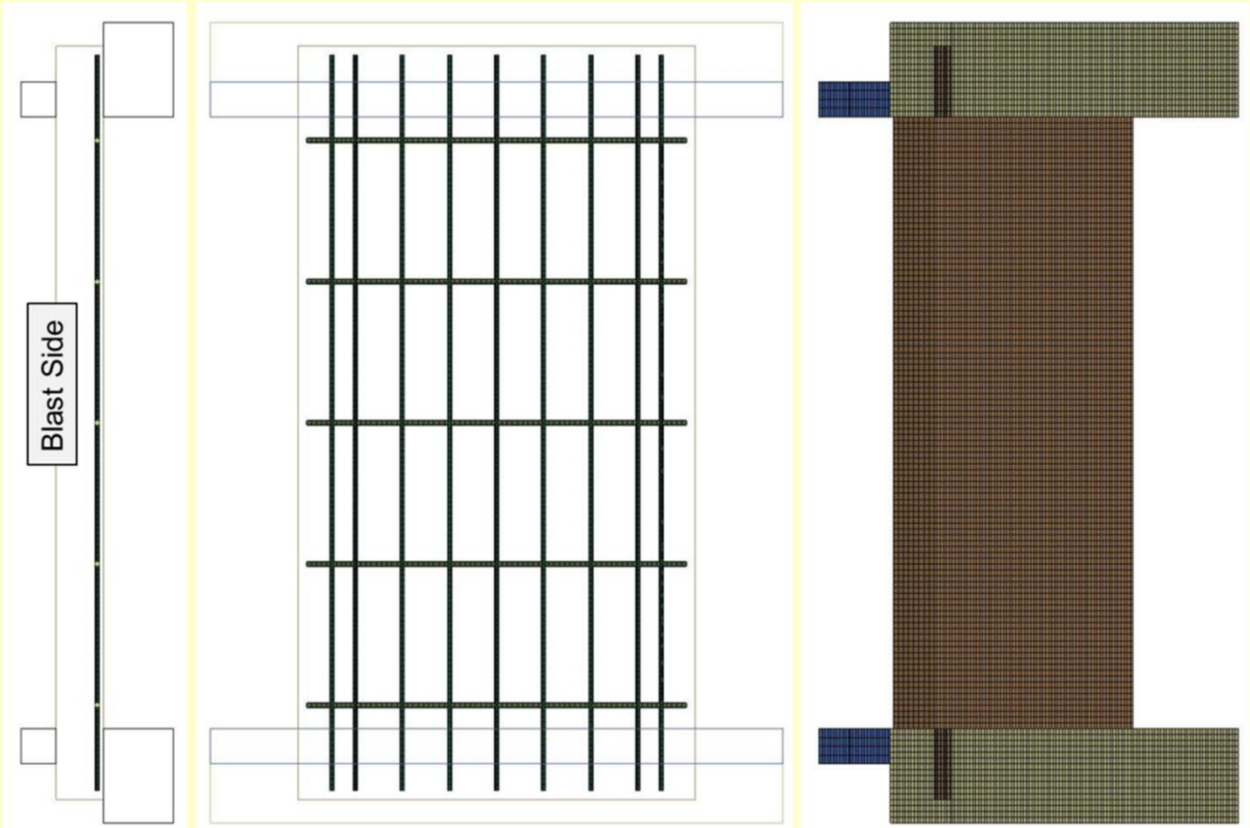
BASELINE MESH



- Element size in the concrete slab of 0.5 inches (12.7mm), or 8 elements thru thickness *[varied]*
- Supports also used 12.7mm shell elements *[contact surfaces]*
- Rebar beam elements nominal length of 12mm with minimum size of 0.4 inches (10.16mm) and a maximum element size of 0.483 inches (12.27mm) *[penalty coupling to concrete]*

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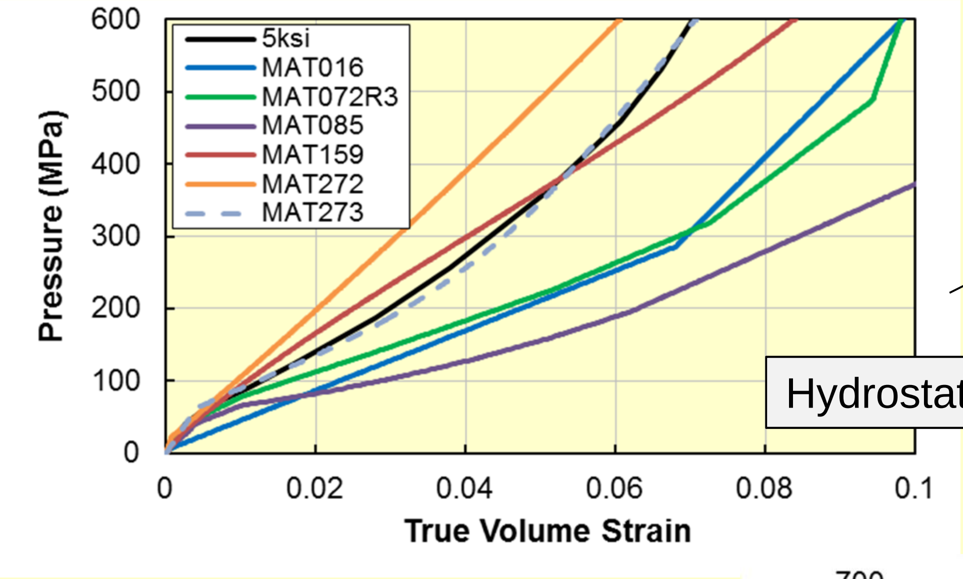
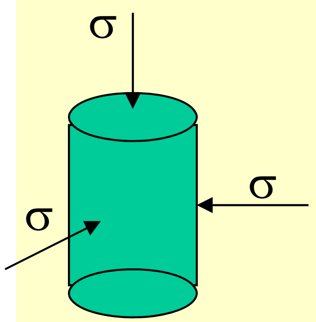
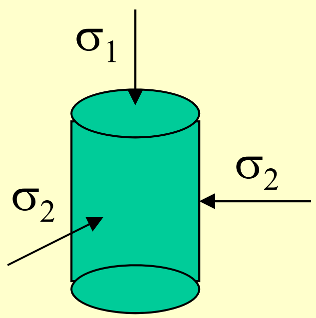
CONCRETE CALIBRATION



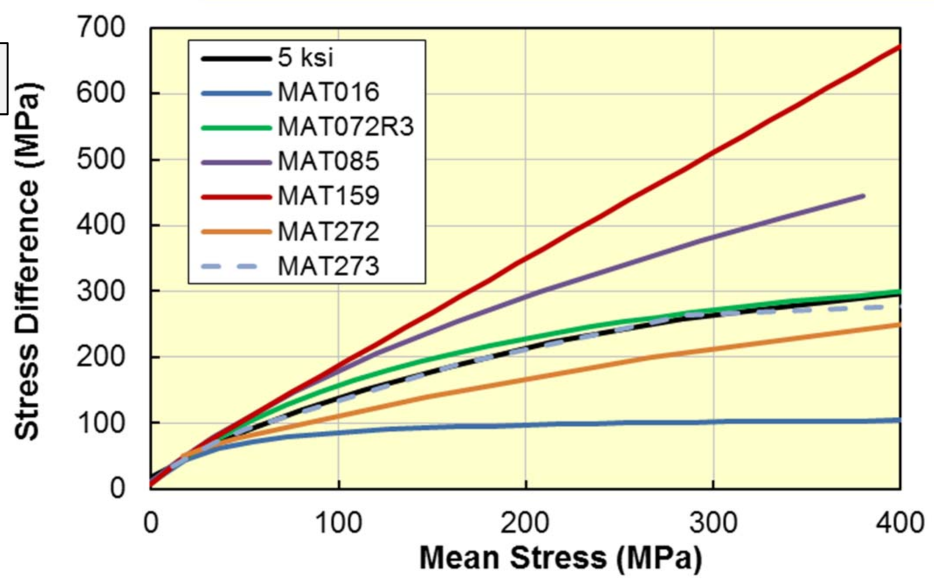


Hydrostatic Compression

Shear Failure Surfaces



$\sigma_1 > \sigma_2$



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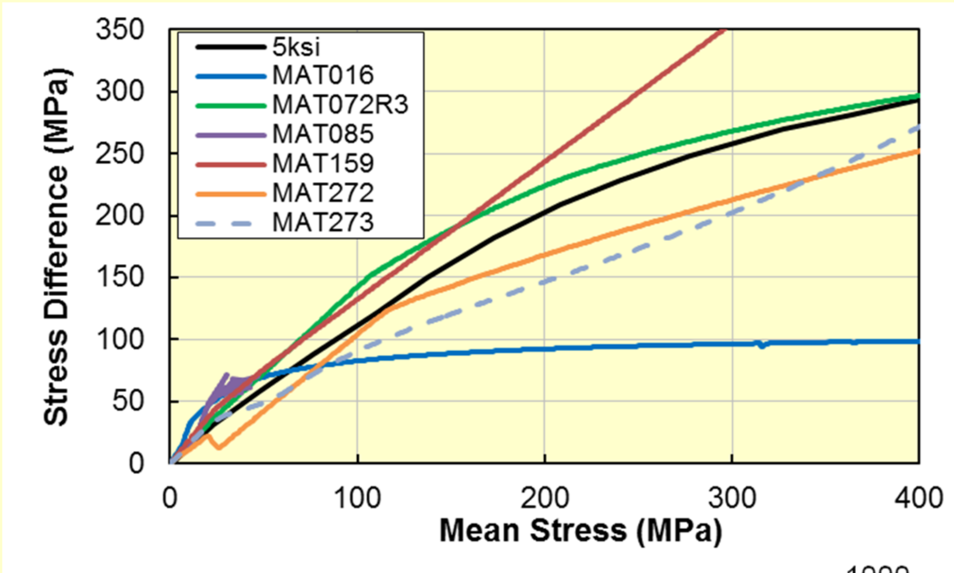
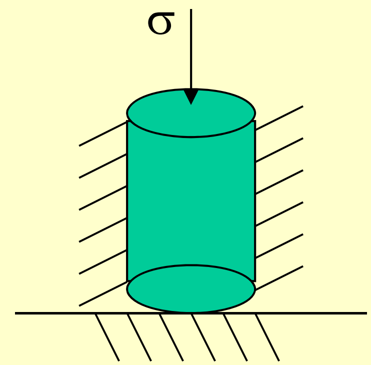
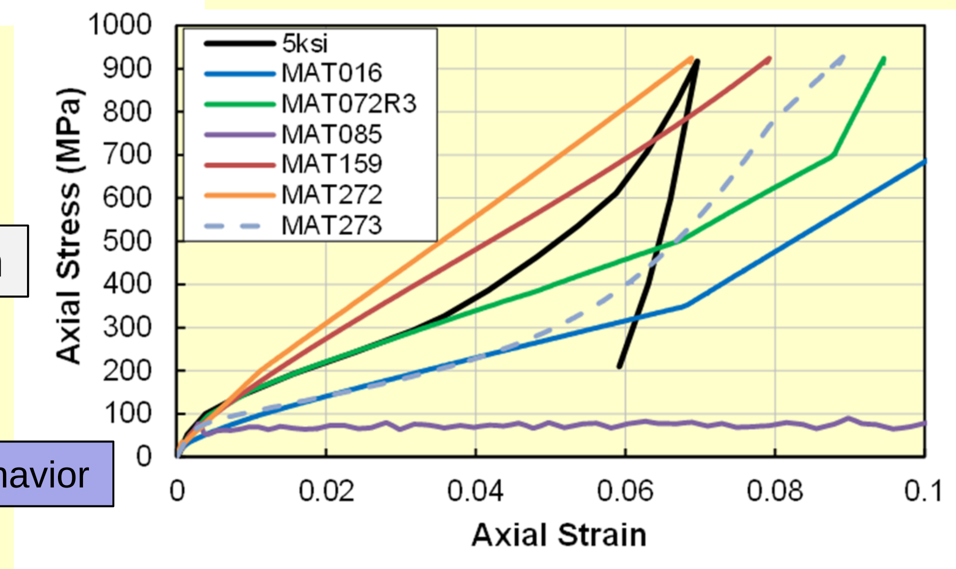
CONCRETE CALIBRATION



Uniaxial Strain Stress Trajectories



Uniaxial Strain Stress-Strain



MAT085 Anomalous Behavior

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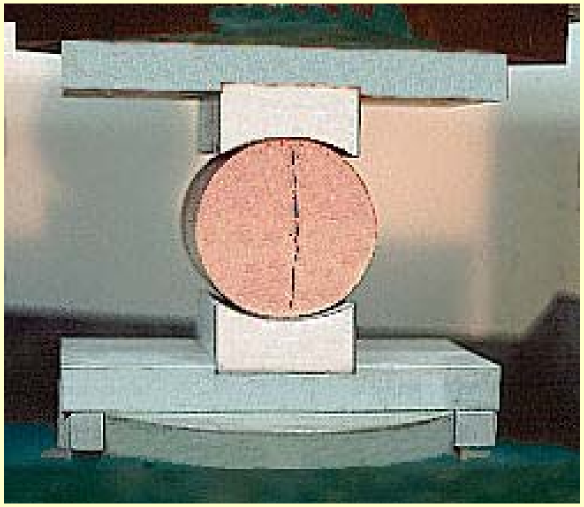
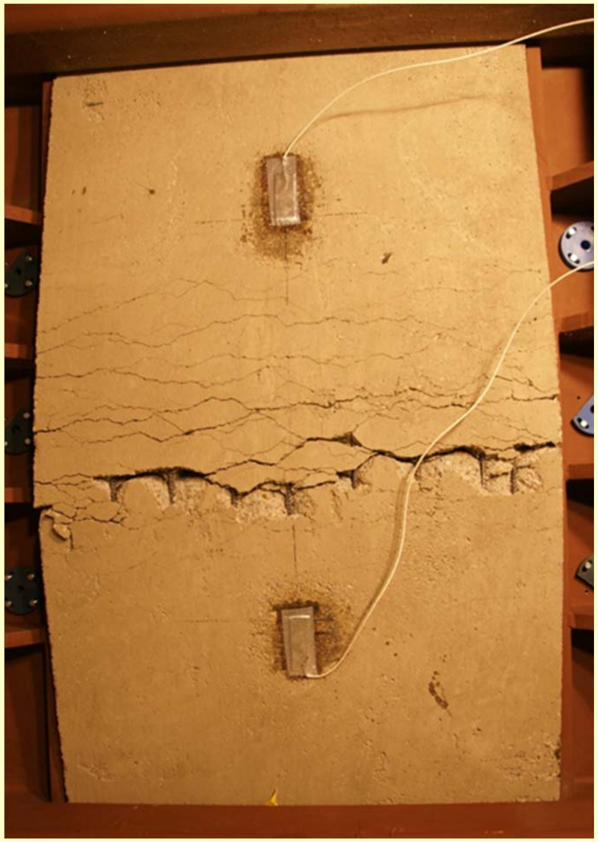
CONCRETE CALIBRATION

Tensile Strength?





Tensile Cracking Dominated Response

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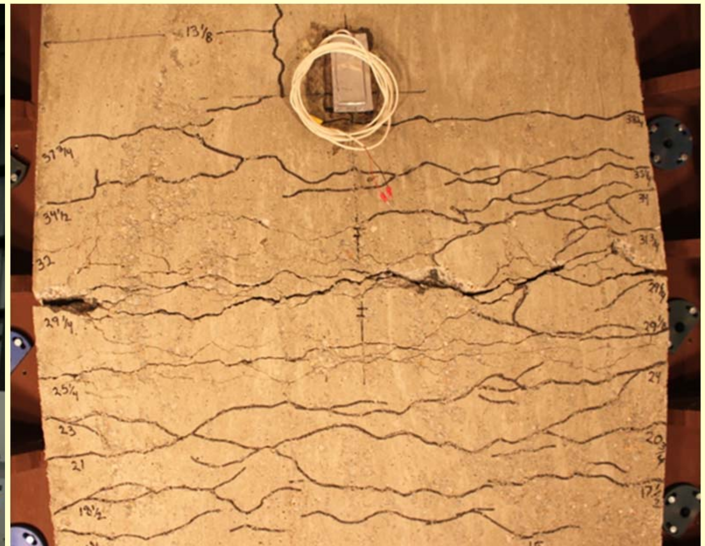
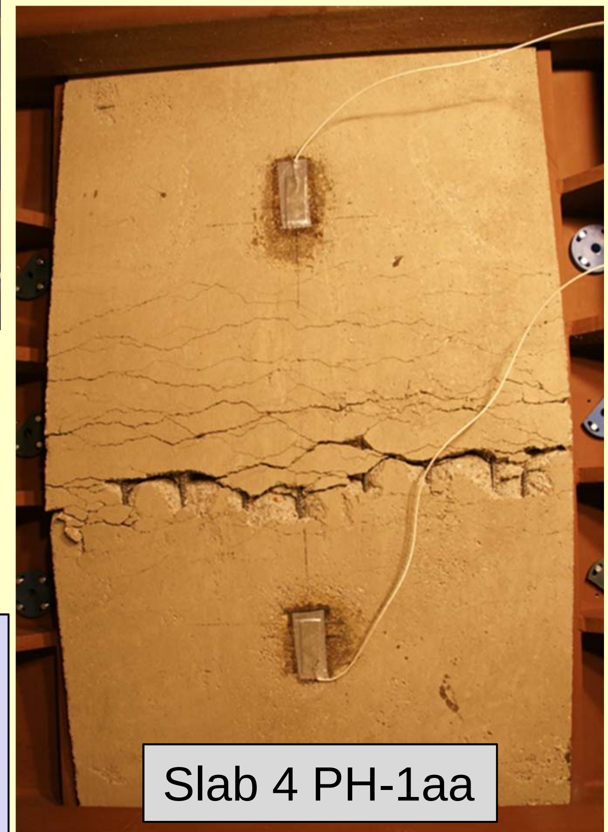
http://www.ibf.uni-karlsruhe.de/felslabor/images/brazilian.jpg

CONCRETE SLAB DEFORMATION & CRACKING



Slab 2 PH-1a

Repeat Test for Loading PH-1a



Slab 4 PH-1aa

Assessment Criteria:

Maximum deflection 4.29 & 4.45 inch (109 & 113 mm)
Time to Maximum 29.4 & 32.4 ms
Residual displacement 3.36 & 3.32 inch (85 & 84 mm)

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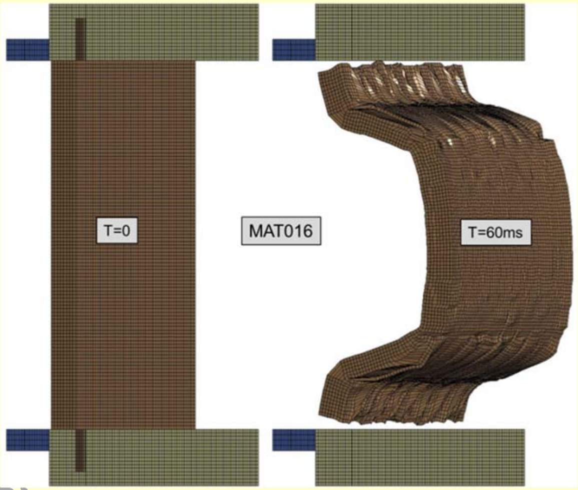
MODEL SLAB RESPONSES

***MAT _PSEUDO_TENSOR (MAT016)**
***MAT _CONCRETE_DAMAGE_REL3 (MAT072R3)**

***MAT_WINFRITH_CONCRETE (MAT084/085)**
***MAT _CSCM_CONCRETE (MAT159)**
***MAT_RHT (MAT272)**



***MAT_CONCRETE_DAMAGE_PLASTIC_MODEL(MAT273)**

While this model did an excellent job of predicting the provided material characterization data, surprisingly it was not able to produce reasonable results for the blast loaded concrete slab simulations. Early on in the loading, at about 11ms, out of an expected 120ms simulation duration, the model reported internal errors.

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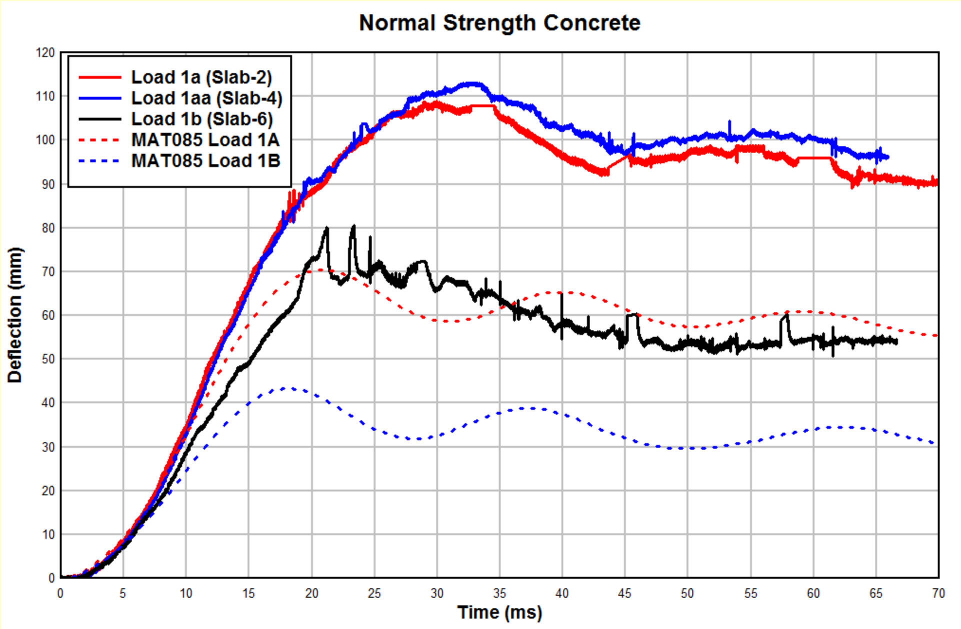
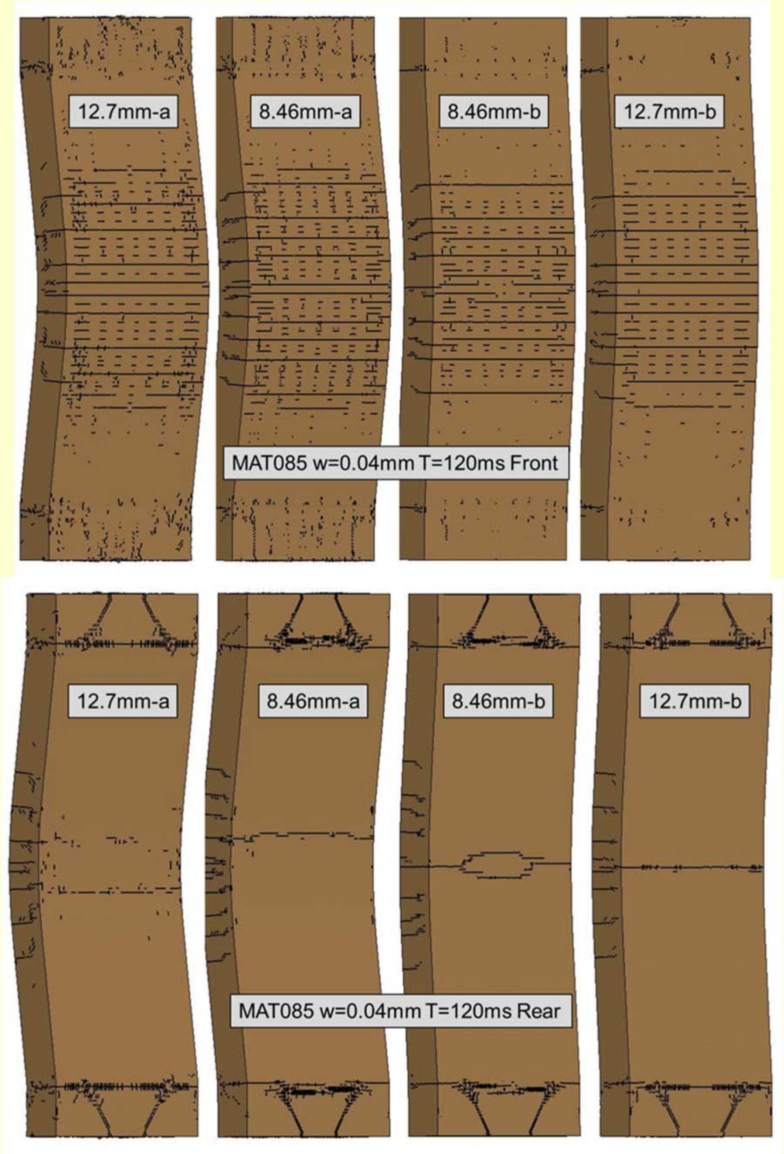
MAT085 WINFRITH CONCRETE MODEL

MAT085 Winfrith Concrete Model
Under Predicted Maximum Displacement
37% PH-1a and 48% PH-1b





Crack Patterns

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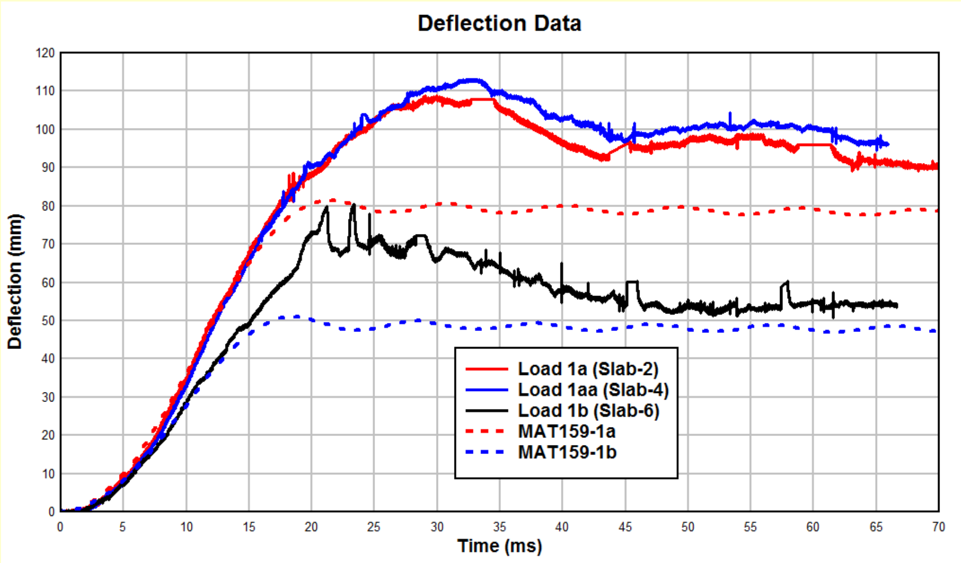
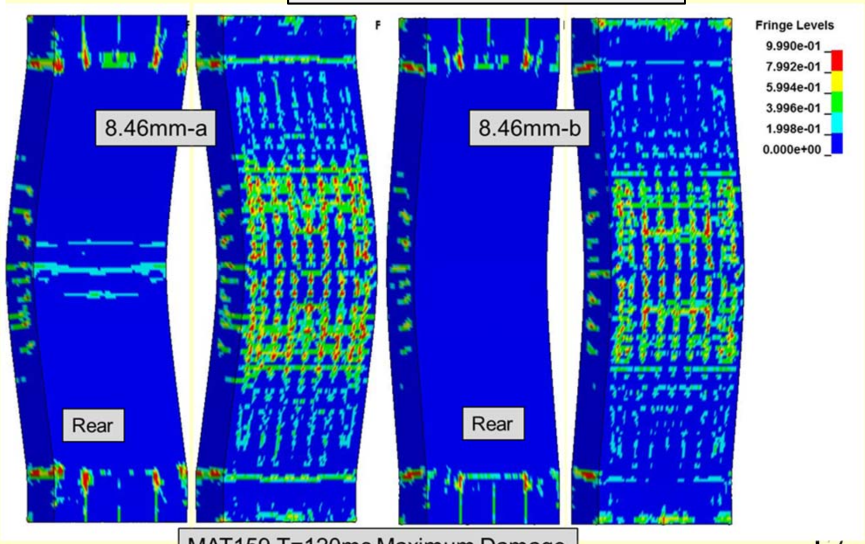
MAT159 CONTINUOUS SURFACE CAP MODEL

MAT159 Continuous Surface Cap Model
Under Predicted Maximum Displacement
27% PH-1a and 38% PH-1b



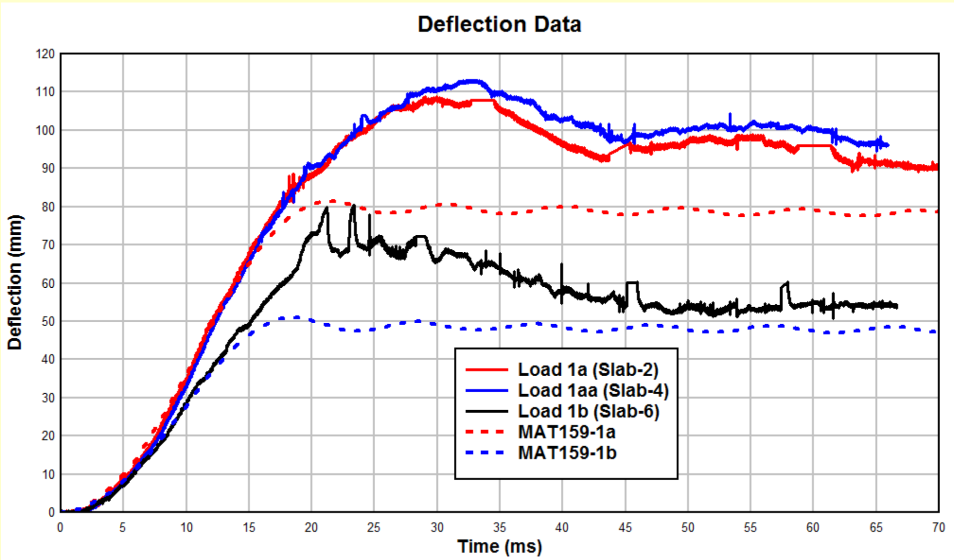
Damage Fringes

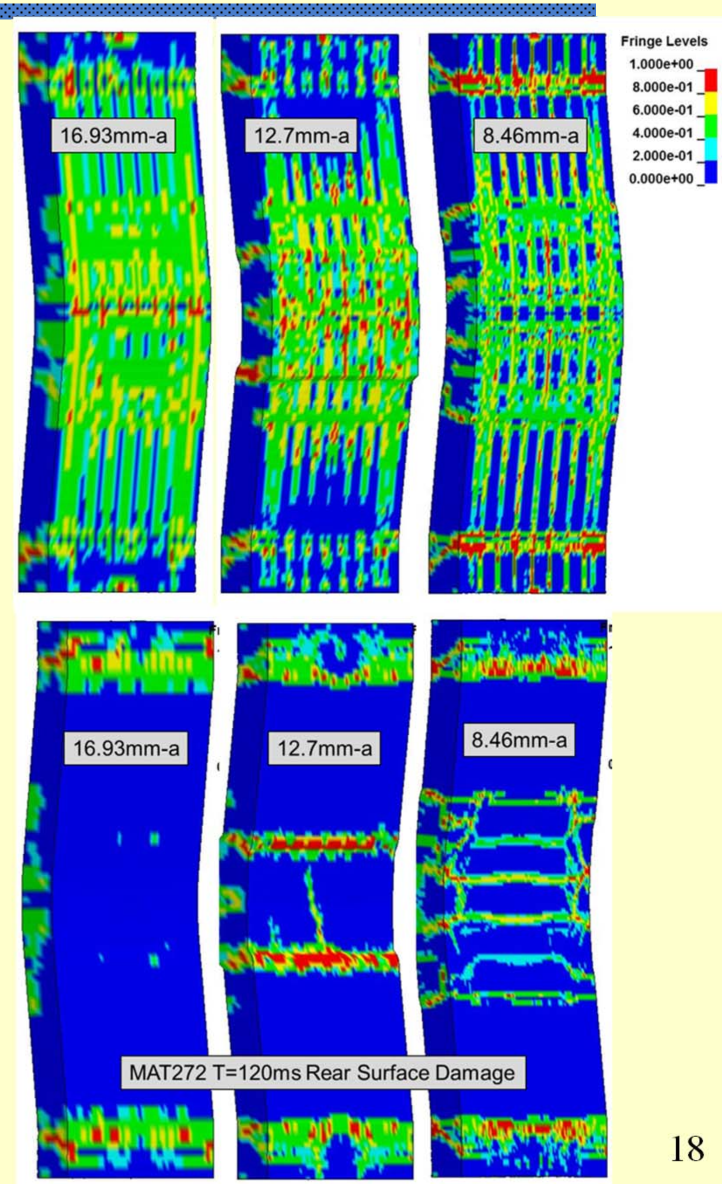


MAT159 T=120ms Maximum Damage

MAT272 RHT CONCRETE MODEL

MAT159 Continuous Surface Cap Model
Under Predicted Maximum Displacement
27% PH-1a and 38% PH-1b





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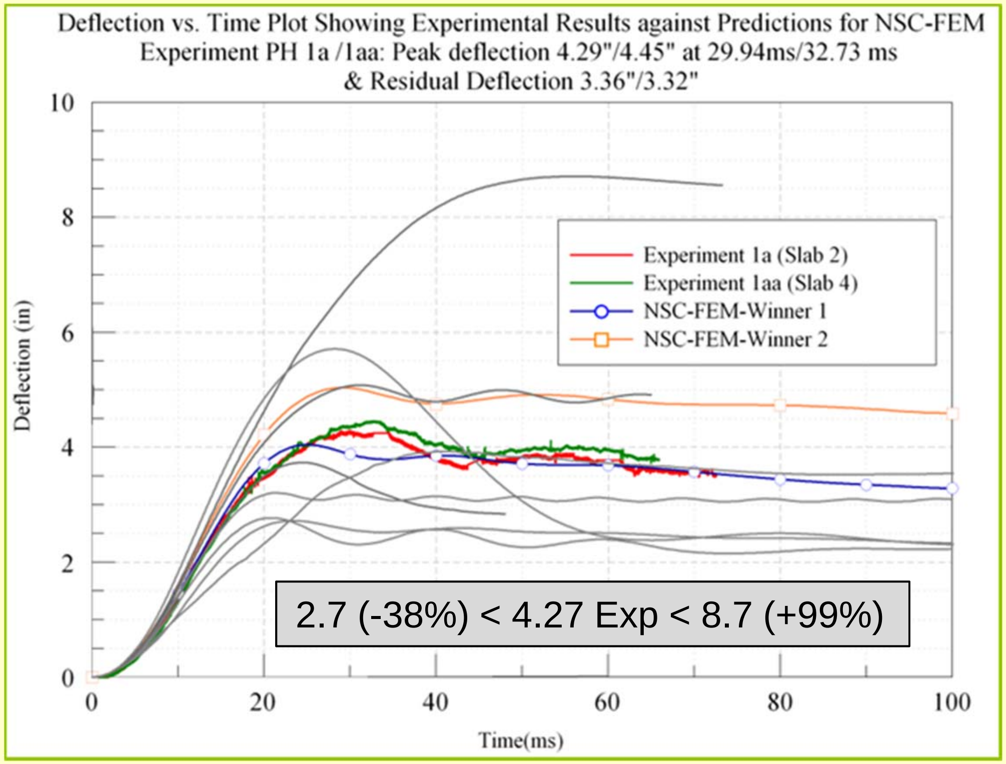
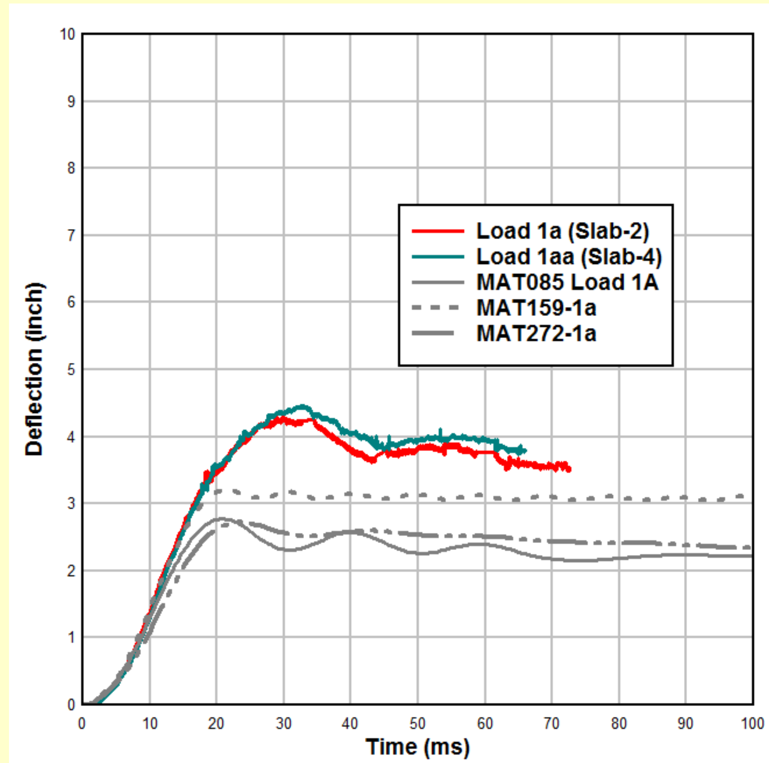
PREDICTIONS PH-1a

Ten predictions (3 by SE&CS) with a First and Second Place award.





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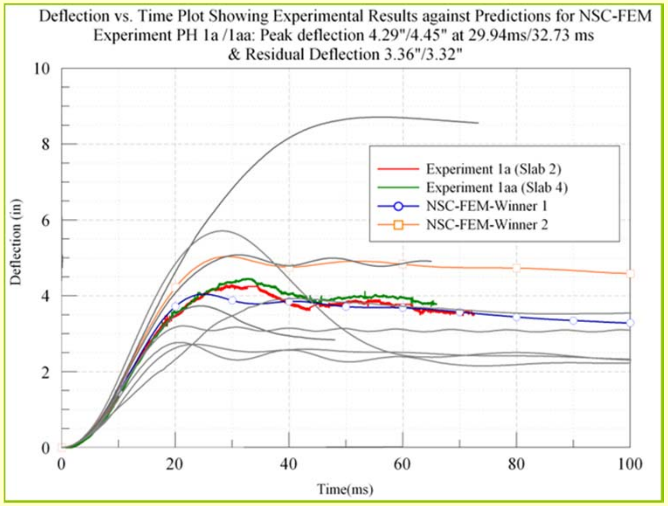
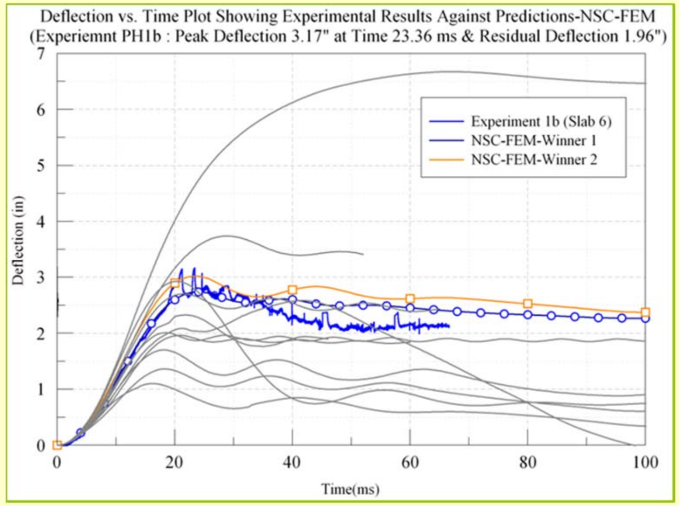
PREDICTIONS OVERVIEW

PH-1a

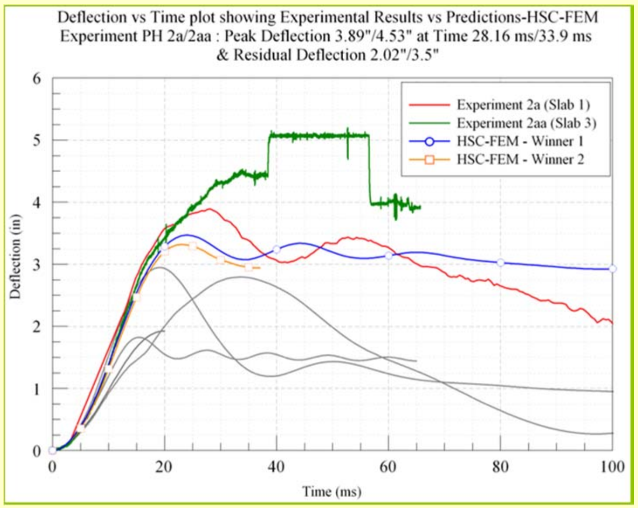
PH-1b

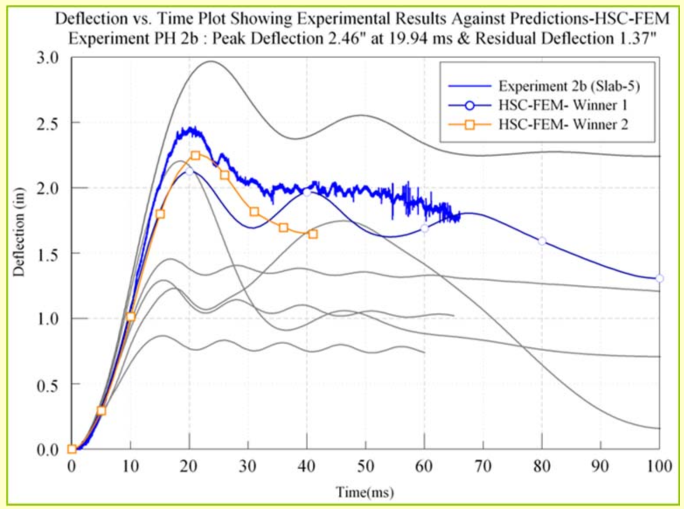
Normal
5ksi (34.5MPa)



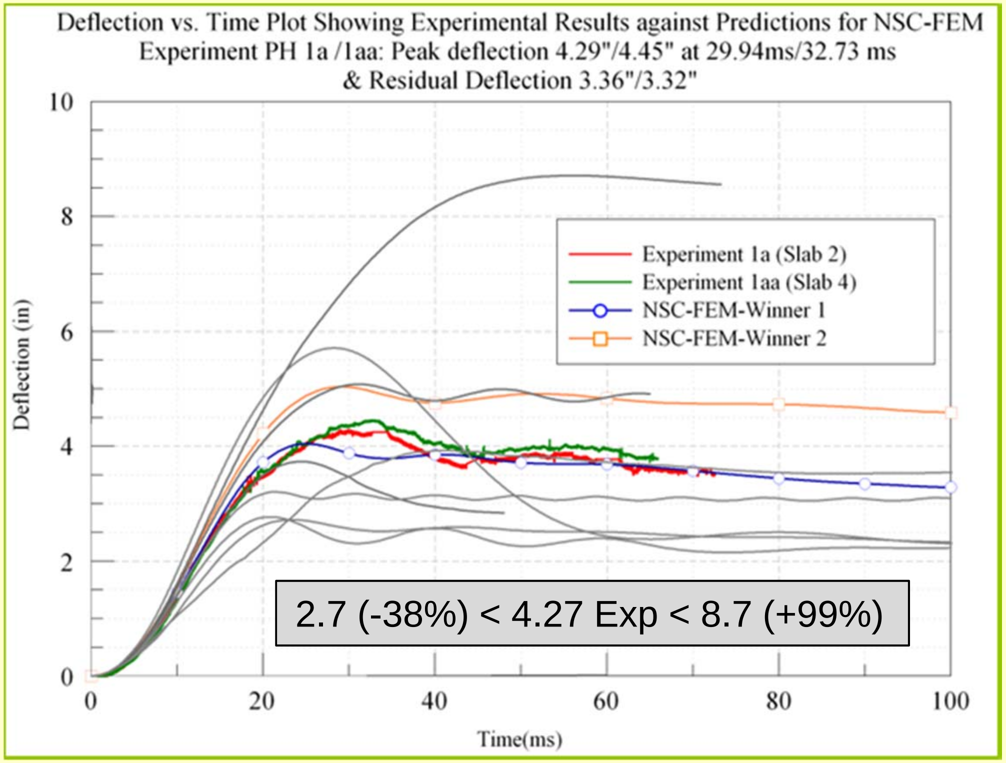


High
15ksi (103.5MPa)





WHAT DID WE LEARN?



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HOW CAN WE LEARN?

Any validation effort has two components: the *quality of the experiments* and the *correctness of the models* – note I did not say accuracy of the models. A model may be incorrect and still produce a result that agrees with an experiment.

To examine the quality of the experimental results – which I believe are quite good in this effort – repeat data is desirable and internal consistence of the data, e.g. strains and displacements appear to be consistent.

To examine the correctness of the models there are three basic options:

1. compare multiple, but different, items with those measured in the experiment, e.g. slab displacement and strains on the surface.
2. independent checks of the model particulars, e.g. inputs and assumptions.
3. model-to-model comparisons – similar to Item 1 above but using outputs from different models of the same problem.

As for model correctness, I asked the ACI presenters who used LS-DYNA to share their input files. Those from universities refused or did not reply. Those from industry shared their input files – this alone is a telling point. The two LS-DYNA models I examined both had errors that when corrected made their comparison with the experimental results less ‘accurate’ than with the errors.

Without the availability of the data and models there is almost nothing to be learned from this effort – there are data and model results and no explicit connection between the two.

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TED BELYTSCHKO, RENOWNED RESEARCHER, SCHOLAR, AND MENTOR, PASSES AWAY

Ted Belytschko, Robert R. McCormick Institute Professor and Walter P. Murphy Professor Emeritus of Mechanical Engineering and Civil and Environmental Engineering, passed away Sept. 15. A member of Northwestern's faculty since 1977, Belytschko was a central figure in the McCormick community and an internationally renowned researcher who made major contributions to the field of computational structural mechanics.

One of the most cited researchers in engineering science, Belytschko developed explicit finite element methods that are widely used in crashworthiness analysis and virtual prototyping in the auto industry. He received numerous honors, including membership in the US National Academy of Engineering, US National Academy of Science, and the American Academy of Arts and Sciences.

Speaking of his students Belytschko said, “The most important thing is to give a lot of freedom because it's remarkable what these young people can do on their own. And if I hadn't let them develop on their own, I don't think I would have the reputation I have. So much of my reputation rests on the contributions of my students.”