SANDFORD FLEMING FORUM

Resilience: Emerging Thinking and Practice

crci

EXPLORA FOUNDATION

Resilience of Infrastructure: High-Strain Rate Loading Effects

Prof. Michael Seica, Ph.D., P.Eng., M.ASCE

October 2014

crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

Outline

- Resilience
- Blast and Impact Loading
- Material Properties Under High-Strain Rate Loading
- Full-Scale Blast Arena Testing
  - Hollow Structural Sections
  - Glazing
- Laboratory Blast Simulator Testing

Resilience

- "The ability to recover from or adjust easily to misfortune or change" (M-W Dictionary)
- Mitigate earthquake effects – vital infrastructures (water, electricity, transportation – lifelines)
- Security from an all-hazards perspective
- Reduce risks of critical infrastructure operations disruption from terrorist attacks

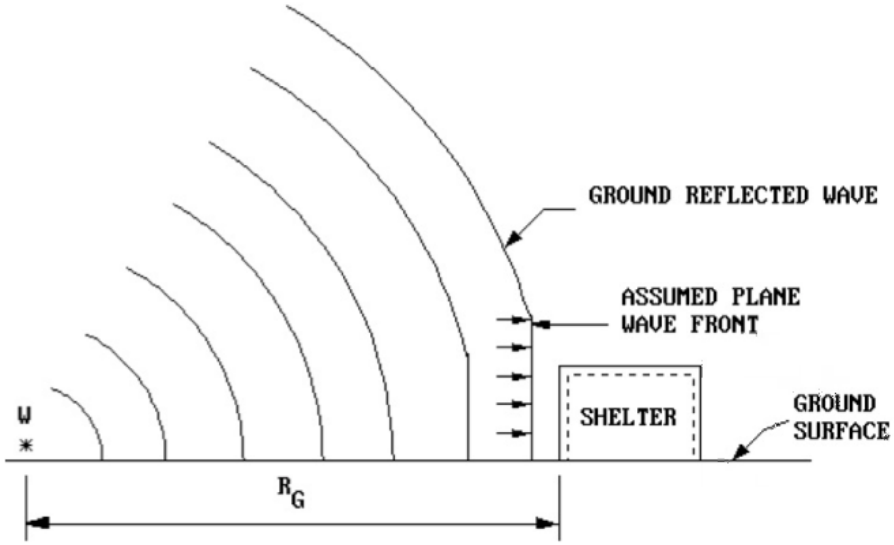
Why Blast

- 85% explosion fatalities from structural collapse
- Glass-breakage related injuries and deaths
- High-strain rate loading
- Goal: Enhance structural resilience to save lives, minimise injuries and protect critical assets

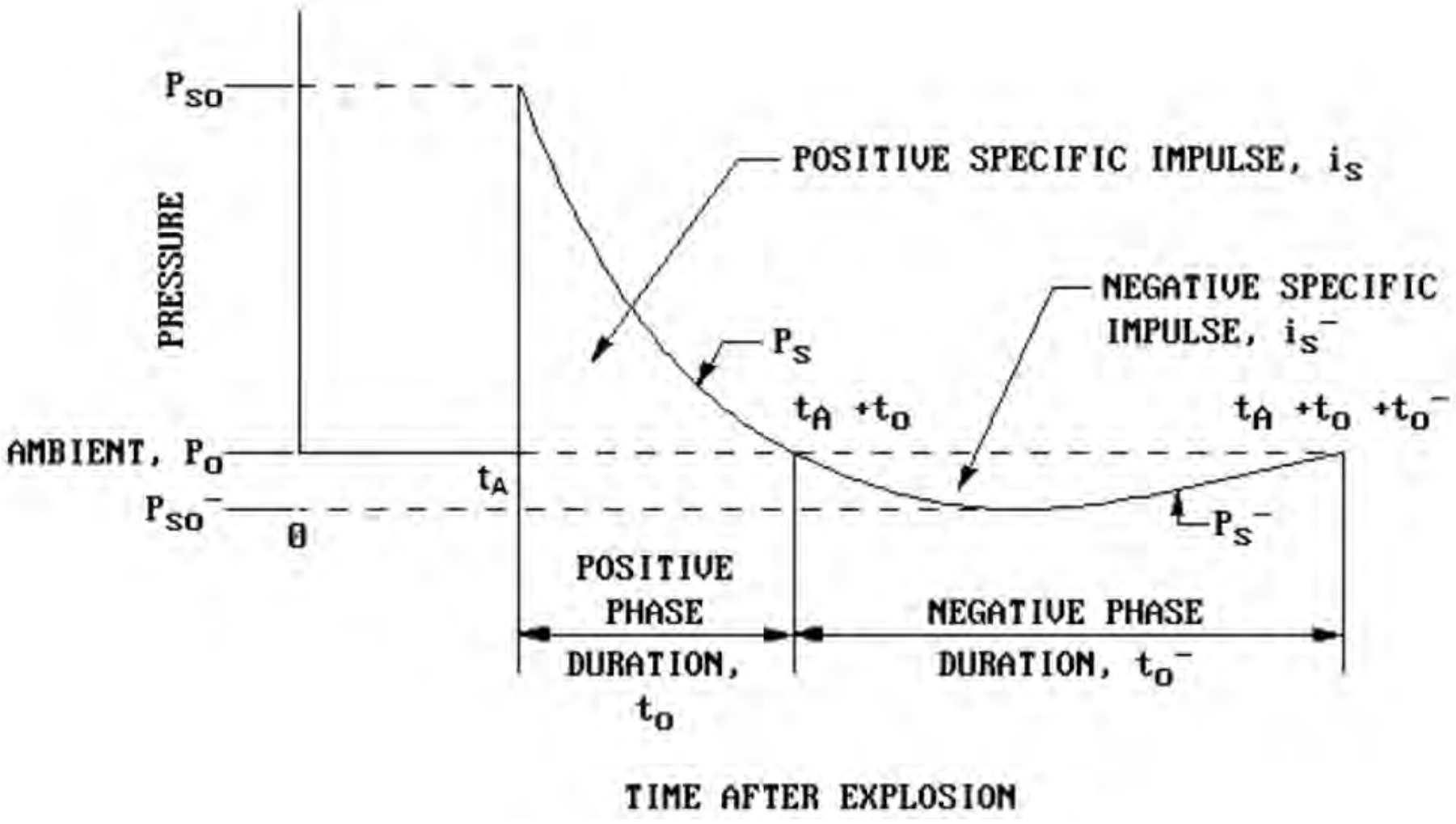
What is a Blast

Detonation: Produced by HEs

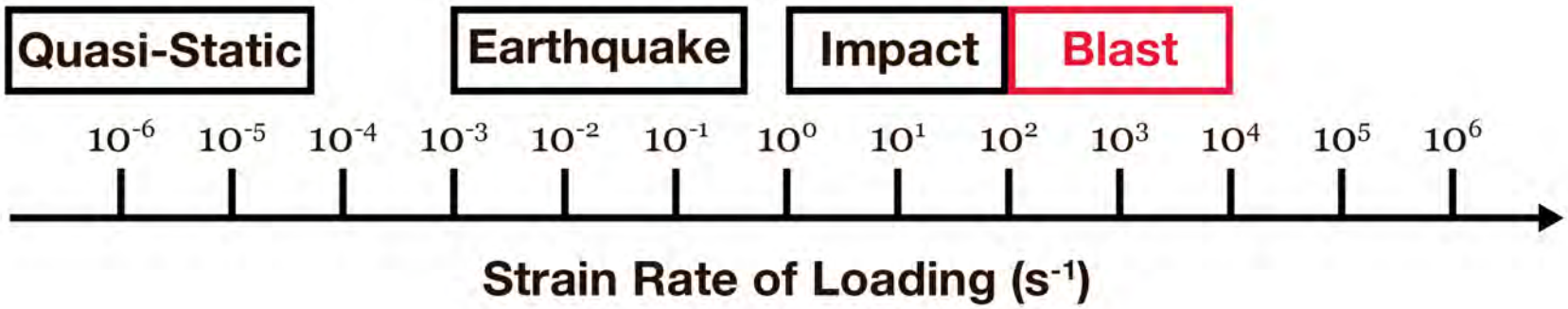
- Blast Wave
- Dynamic Pressure
- Fragmentation
- Ejecta
- Ground shock
- Fire

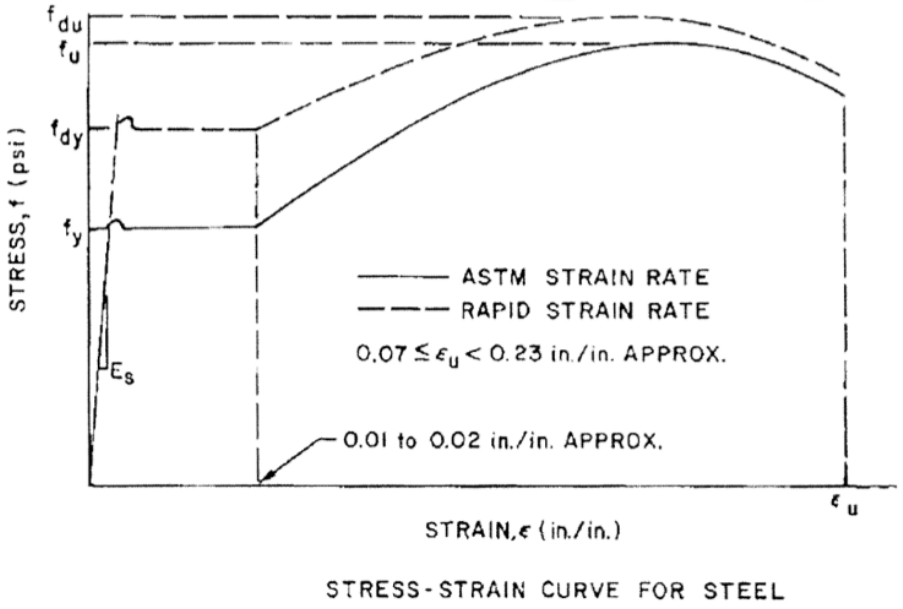


Blast Wave Properties

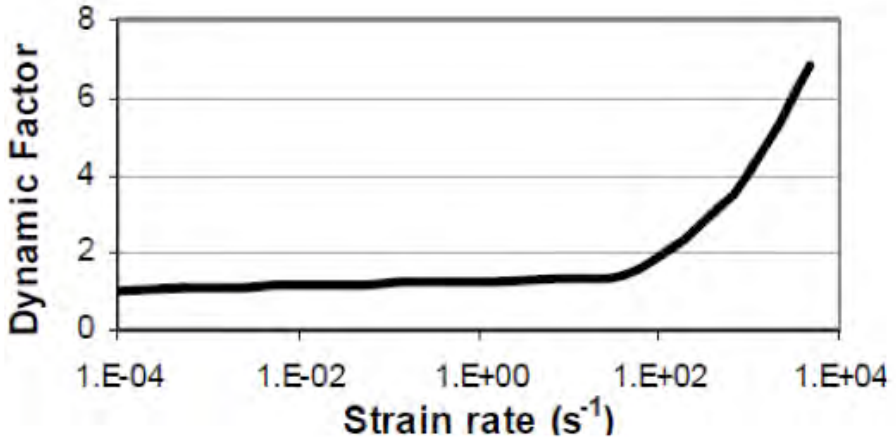


Dynamic Material Properties





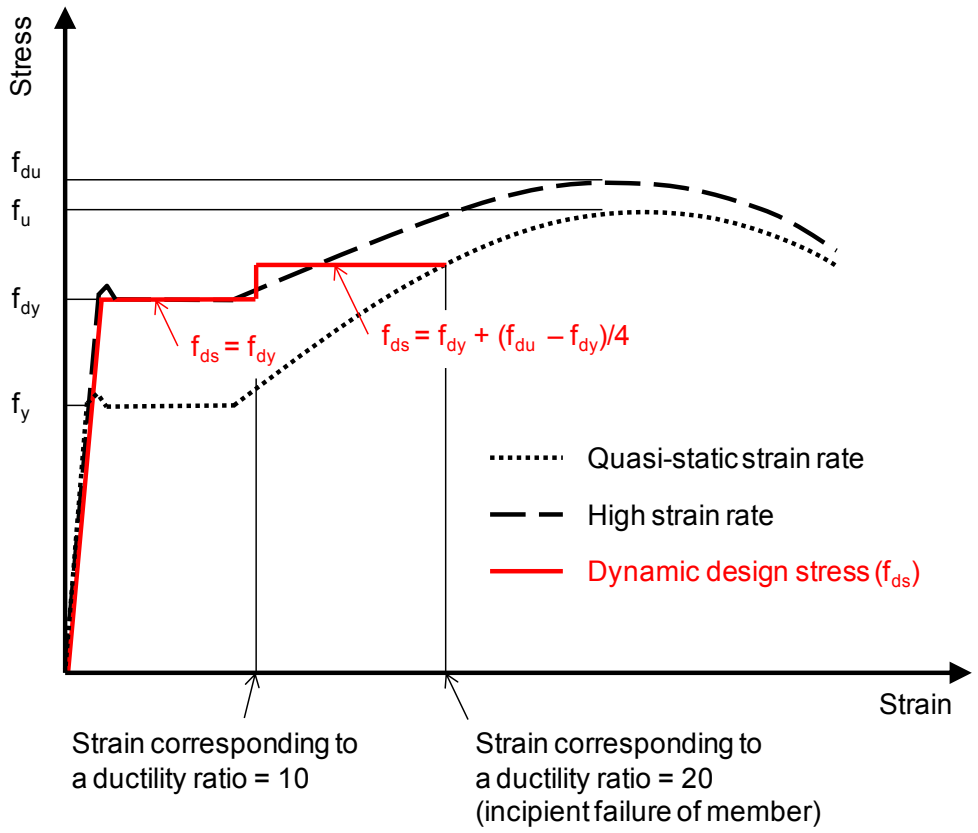
STRESS-STRAIN CURVE FOR STEEL



Why Hollow Structural Sections (HSS)

- Blast loading may be imposed from any direction
- HSS are symmetric and have no “weak axis” in bending
- Inherent high torsional rigidity
- Composite concrete-filled HSS members becomes possible

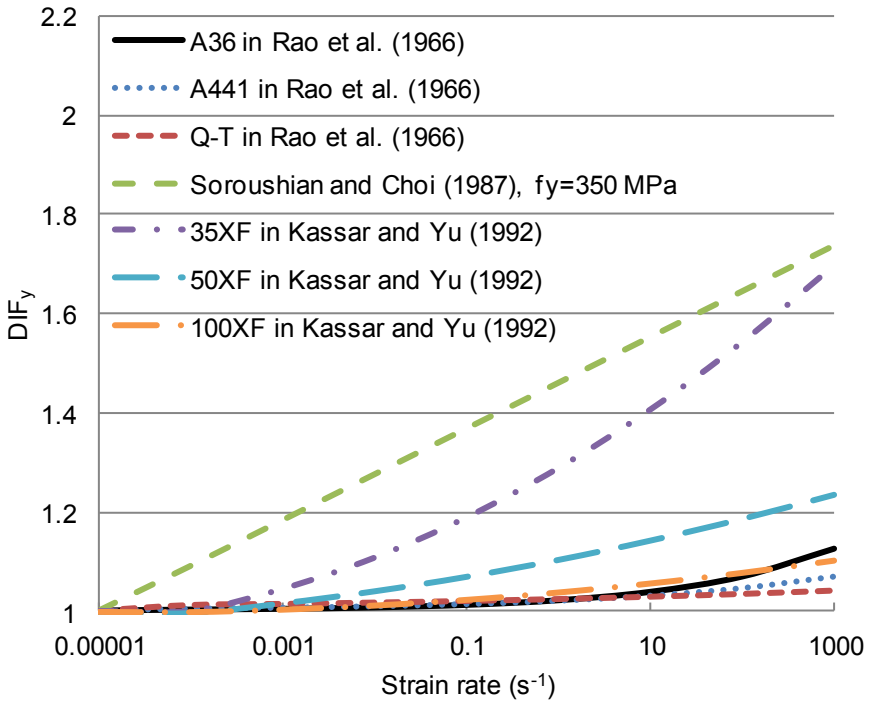
Dynamic Design Stress for Steel

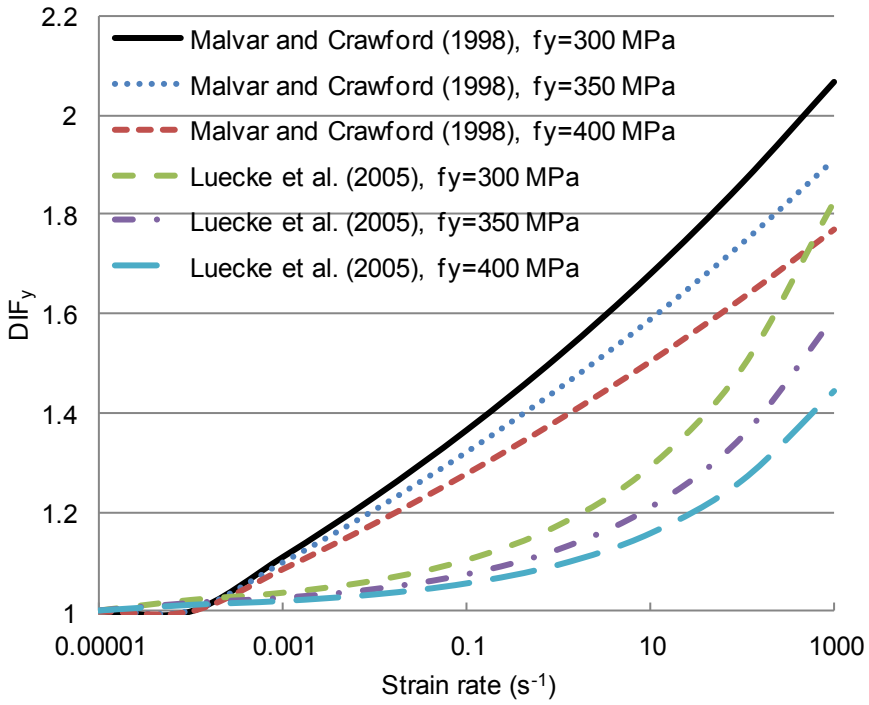


ASTM specifications	DIF_y		DIF_u
	Bending / Shear	Tension / Compression	
A36	1.29	1.19	1.10
A588	1.19	1.12	1.05
A514	1.09	1.05	1.00
A446/A653	1.10	1.10	1.00
A572	1.19	1.10	1.00
A992	1.19	1.10	1.00

Dynamic Design Stress for Steel (UFC 3-340-02)

Steel Dynamic Increase Factor (DIF)

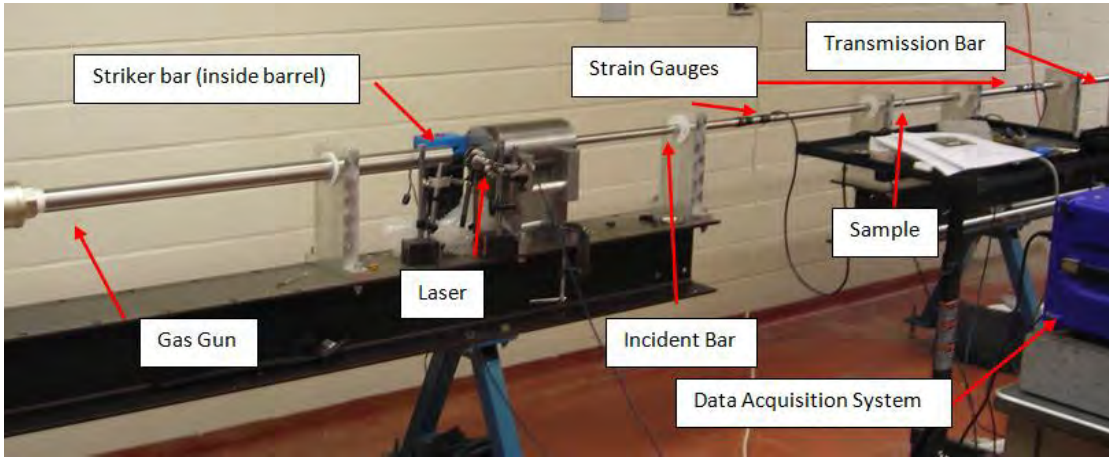


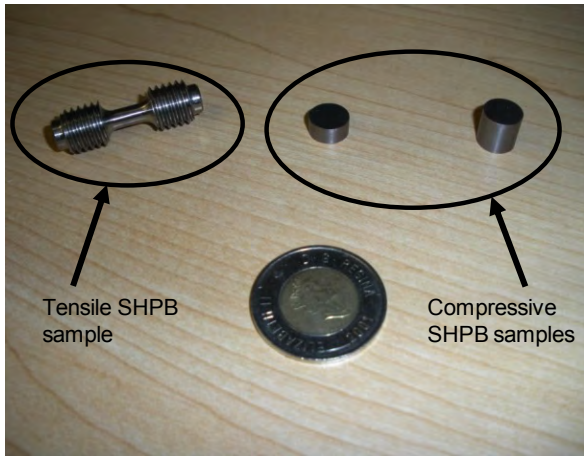


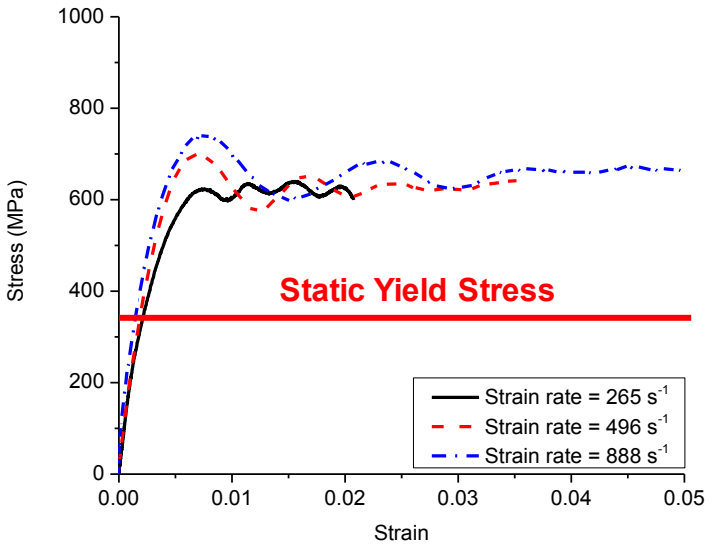
Relationships between DIF_y and strain rate of various steels from previous investigations

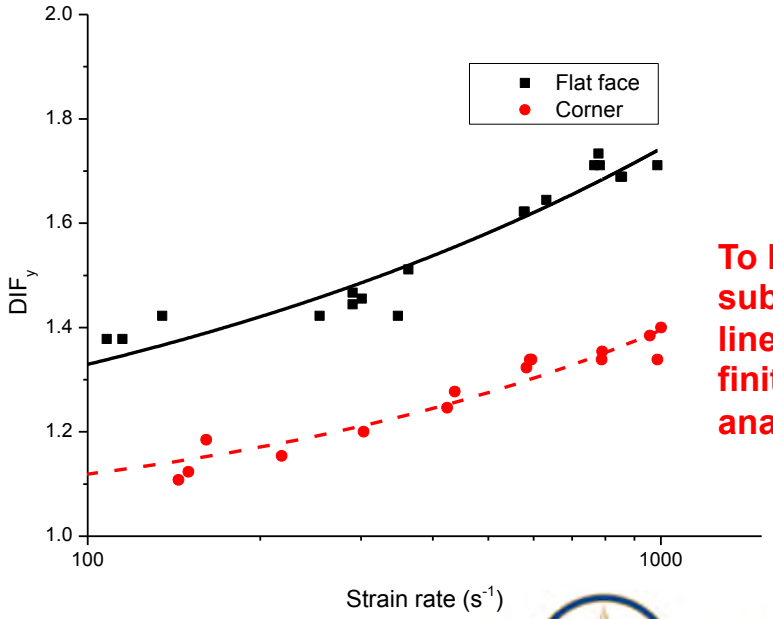
Investigations on the high strain rate behaviour of HSS are scarce.

Split Hopkinson Pressure Bar Testing





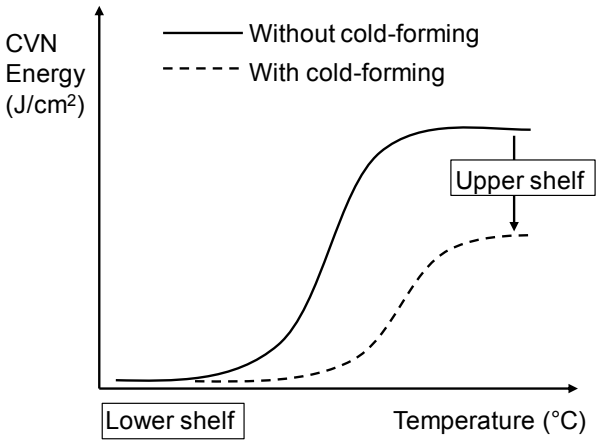




To be used in the subsequent non-linear dynamic finite element analysis

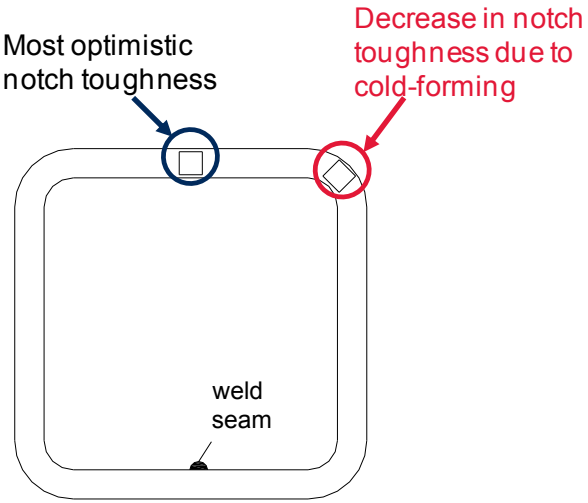
Charpy V-Notch Impact Tests

Cracking in-service
(low temperature or **dynamic loading**)

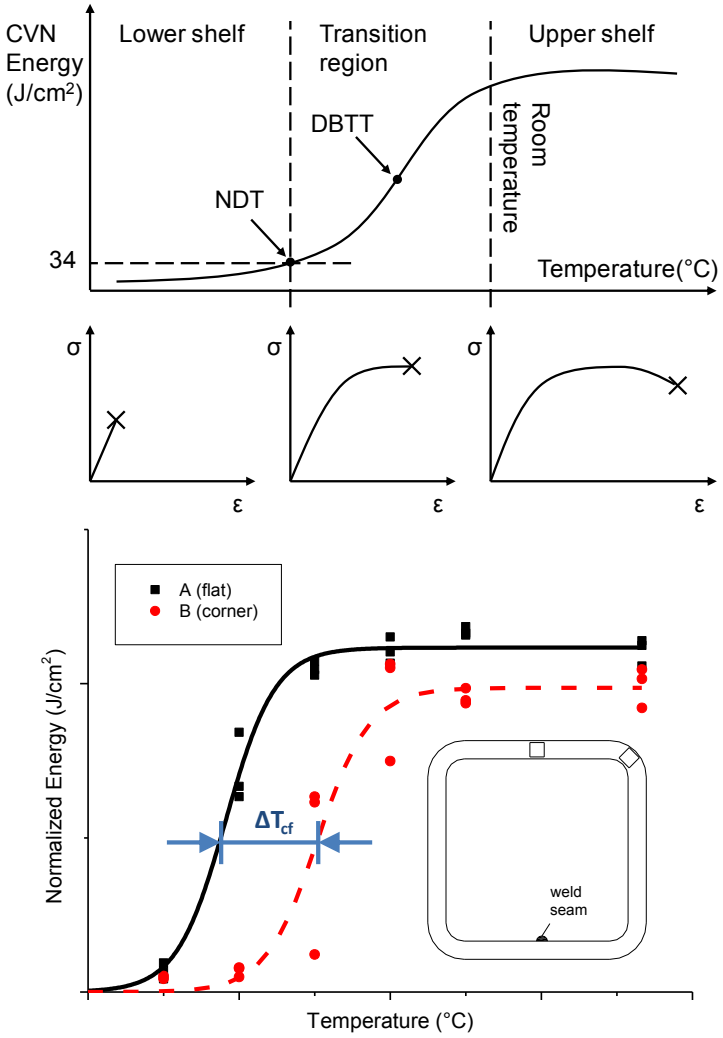


HSS product standards
- ASTM A500-10
- ASTM A1085-13
- CAN/CSA G40.20-13/G40.21-13
- EN 10219:2006
- ISO 10799-1

International design standards
- AASHTO
- CSA S16-09
- EN 1993-1-10:2005



Charpy V-Notch Impact Tests



DBTT = Ductile-to-Brittle Transition Temperature

NDT = Nil-Ductility Temperature

For notch toughness,

Corner = weak spot

Blast Arena Testing

crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

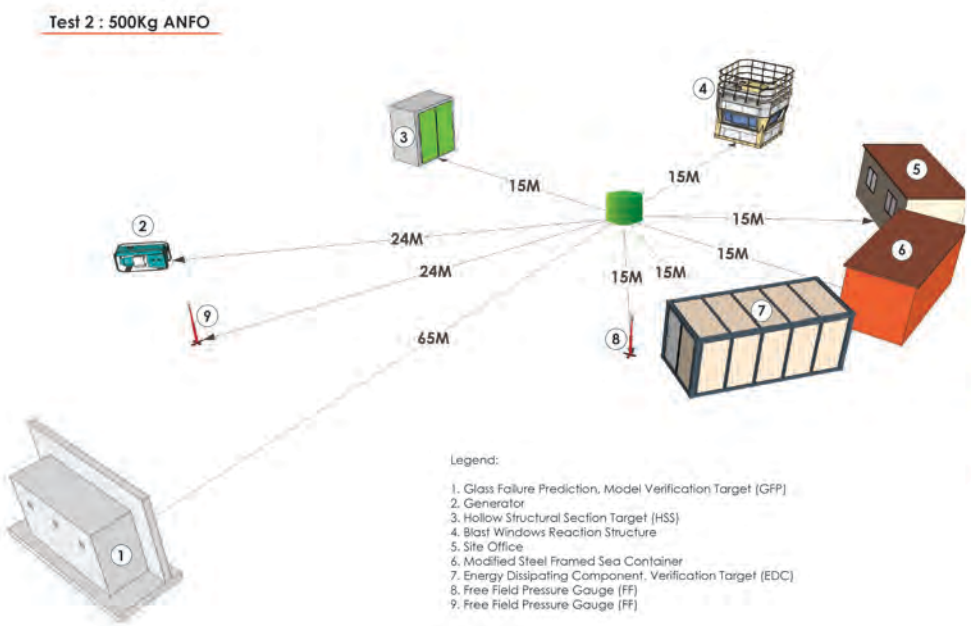
Blast Arena Testing

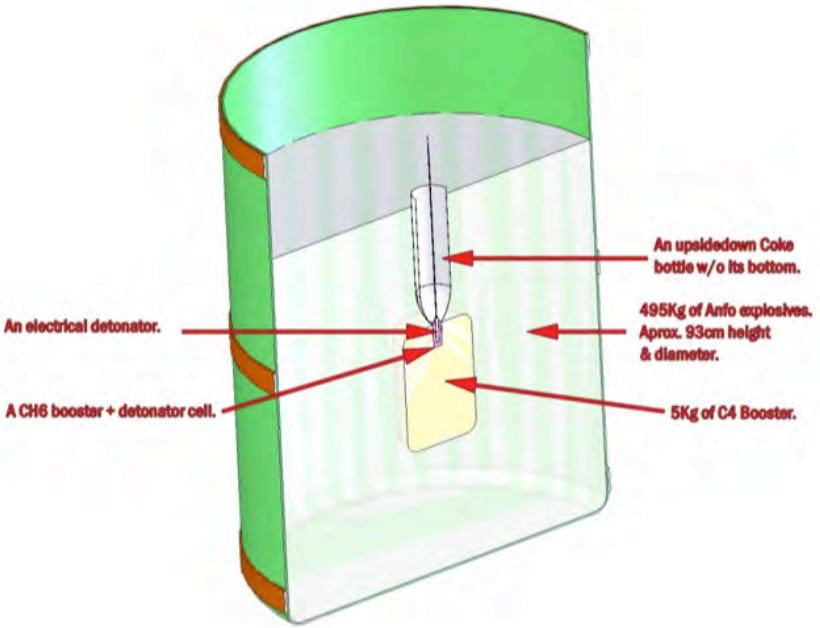
Blast Arena Testing

crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

2012 Test Series Overview

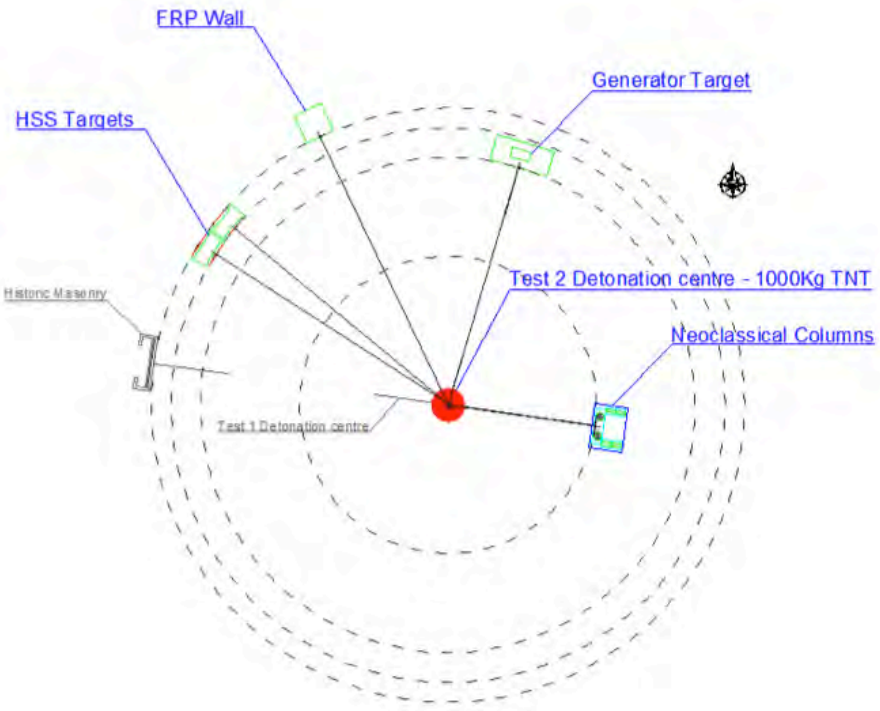




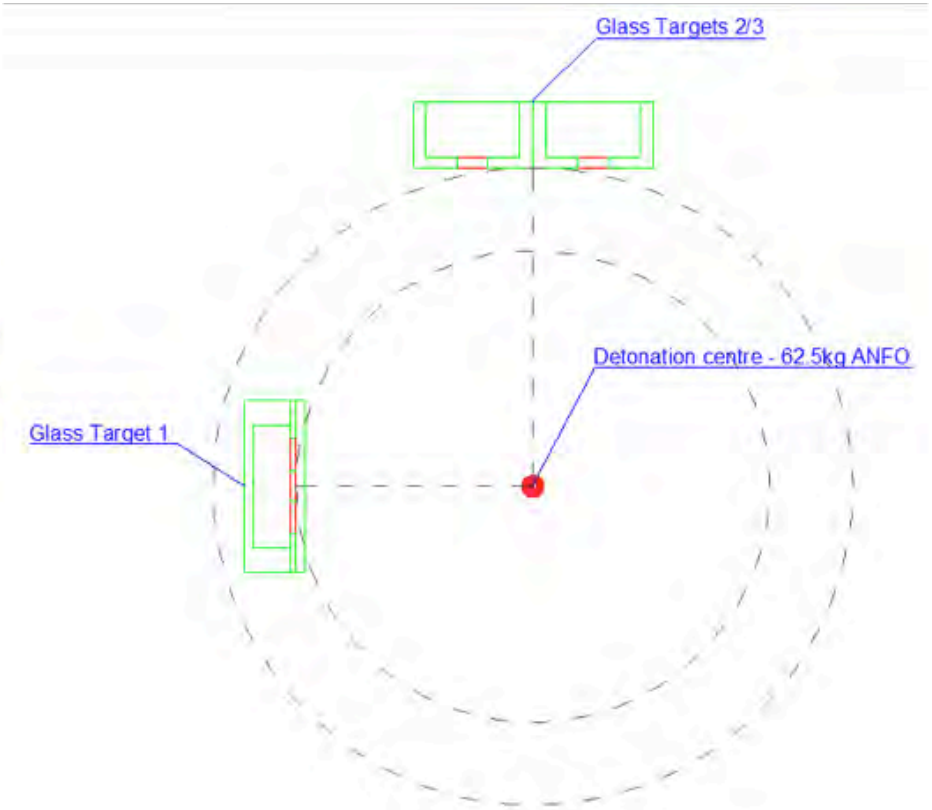
crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

2013 Test Series Overview



Test 2
Tuesday 4th June



Glass Test
Wednesday 29th May

crci | The Centre for Resilience of Critical Infrastructure

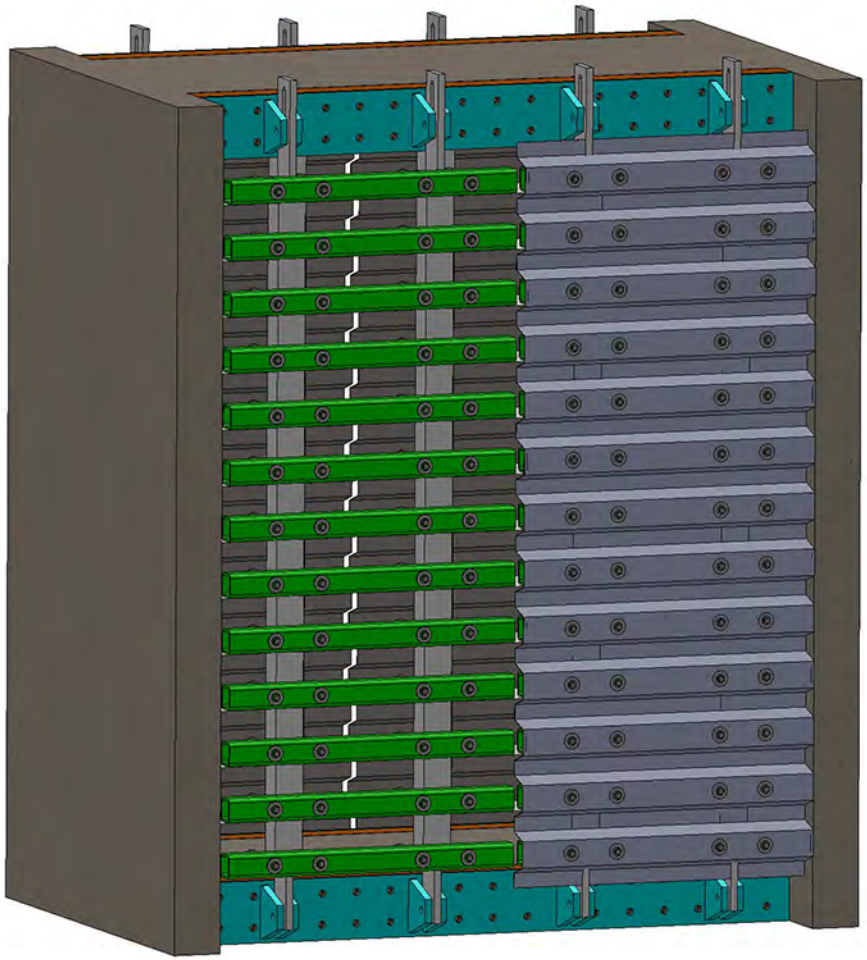
EXPLORA FOUNDATION

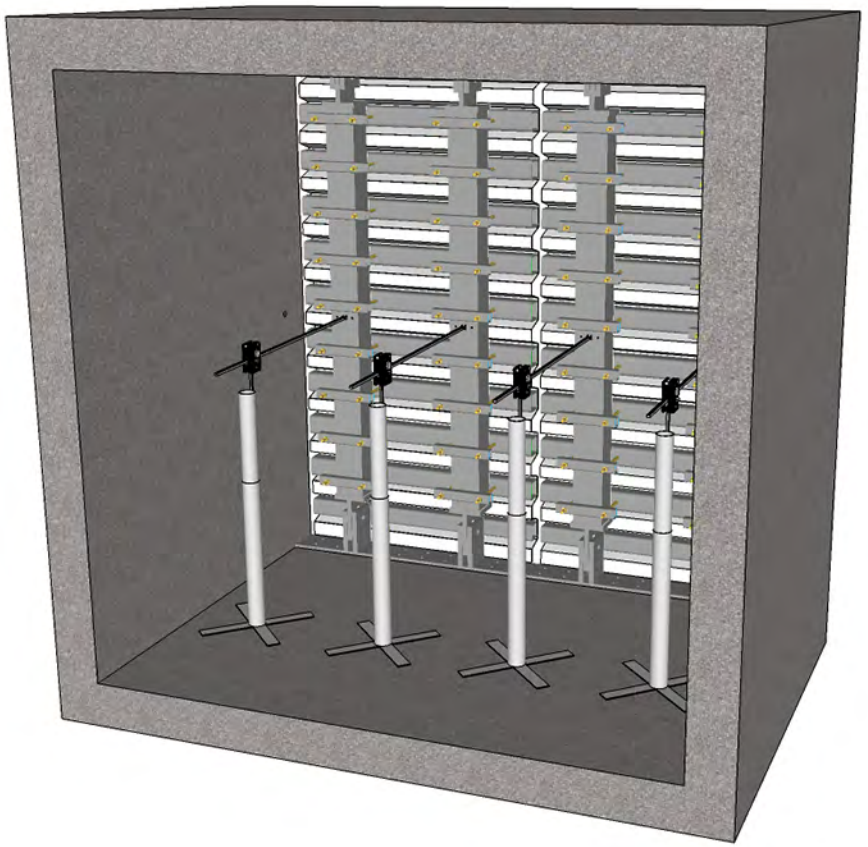
Test Series Charges

crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

Hollow Structural Section Target





crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

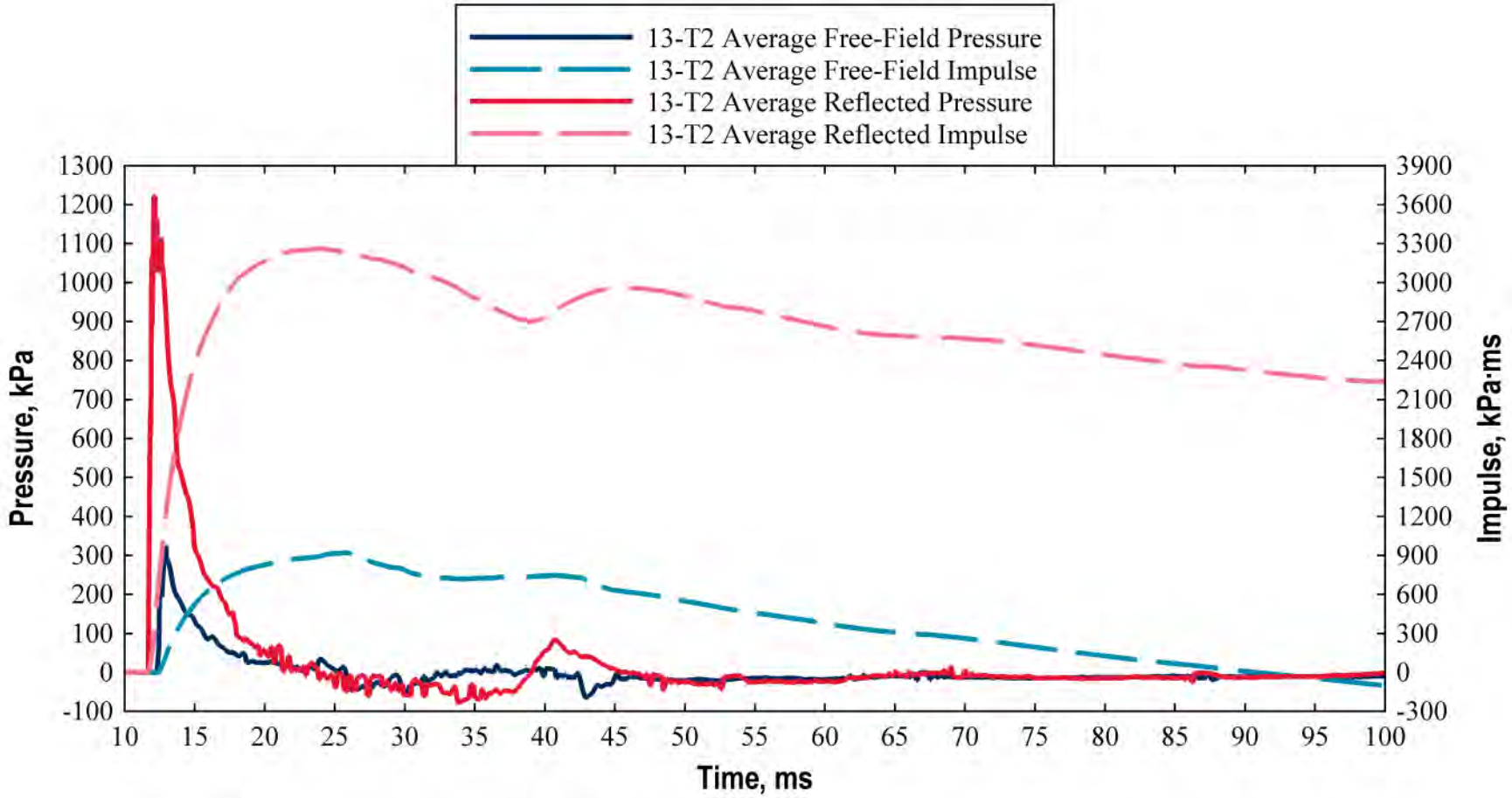
HSS Targets Before Test – Exterior

HSS Targets Before Test – Interior

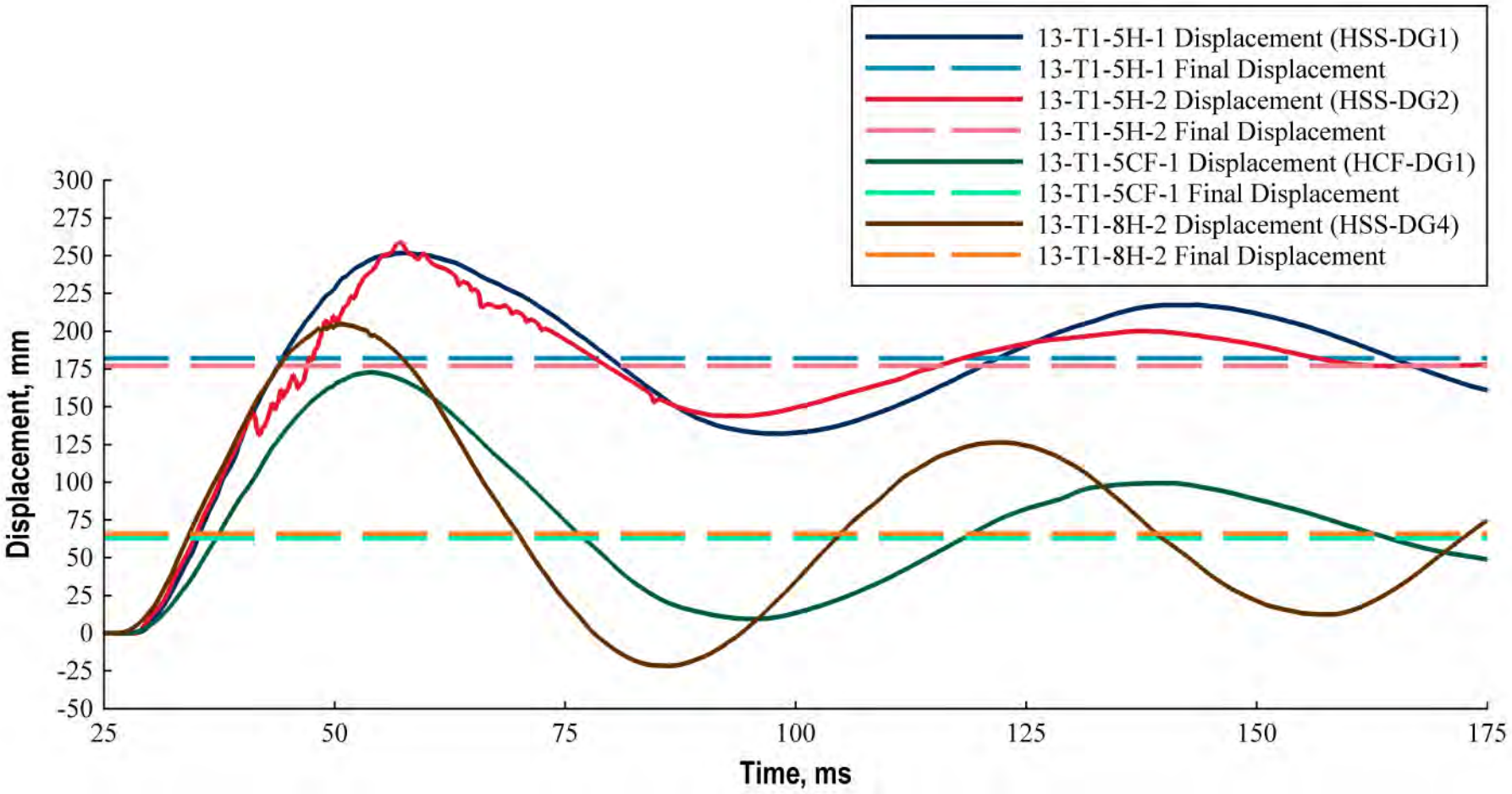
HSS Targets After Test – Exterior

HSS Targets After Test – Interior

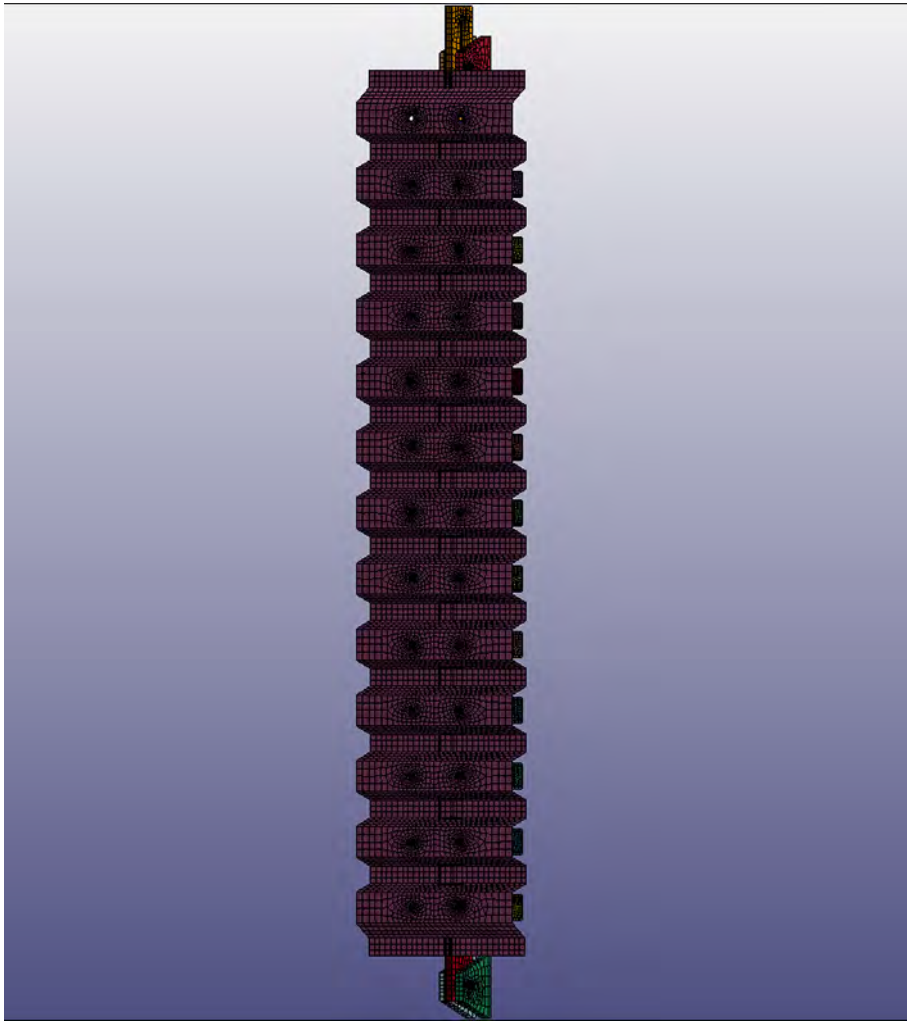
HSS Targets Reflected Pressure-Time History

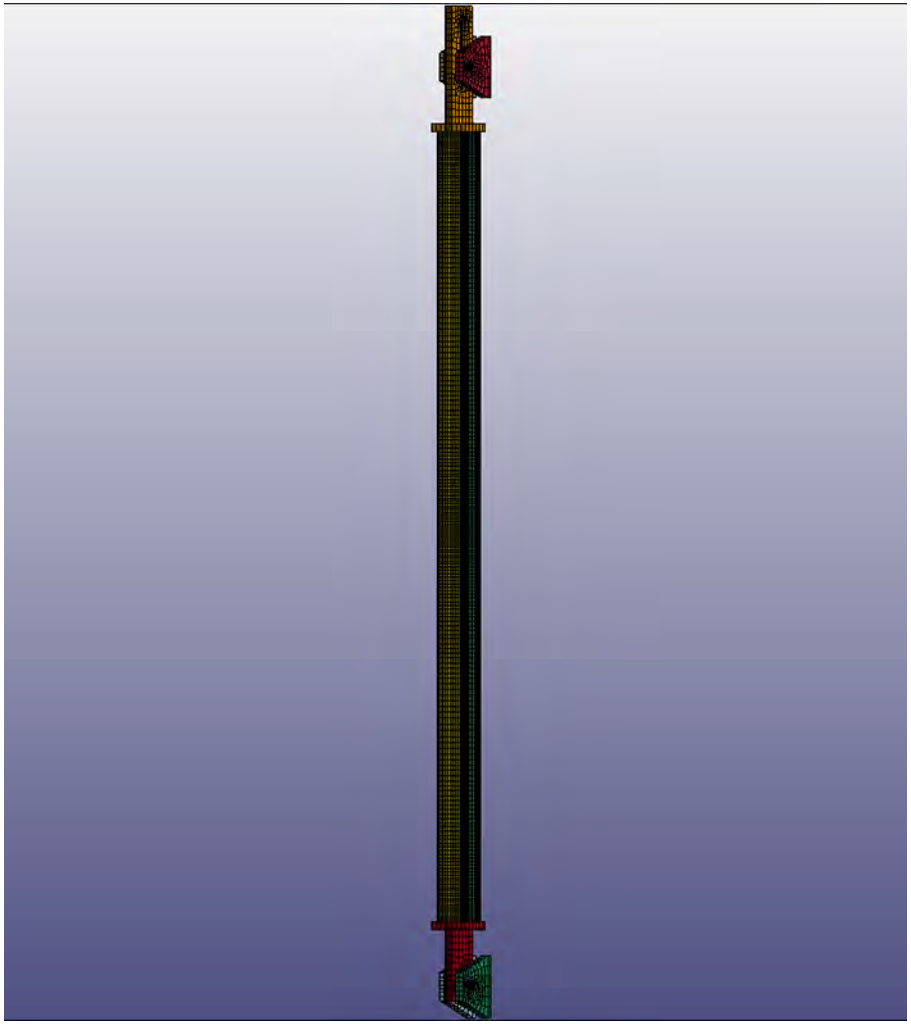


HSS Targets Displacement-Time History

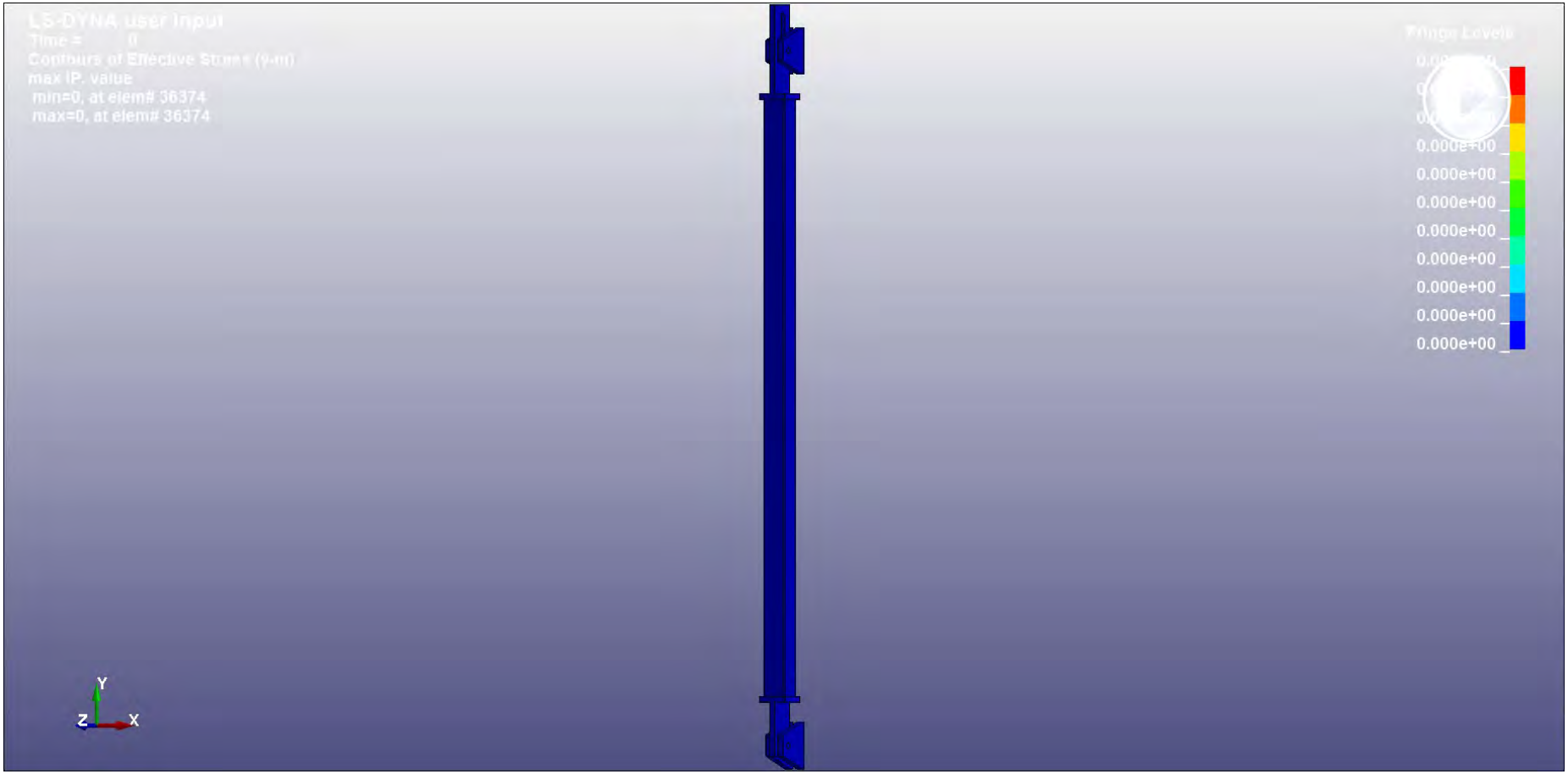


Explicit Finite Element Analysis





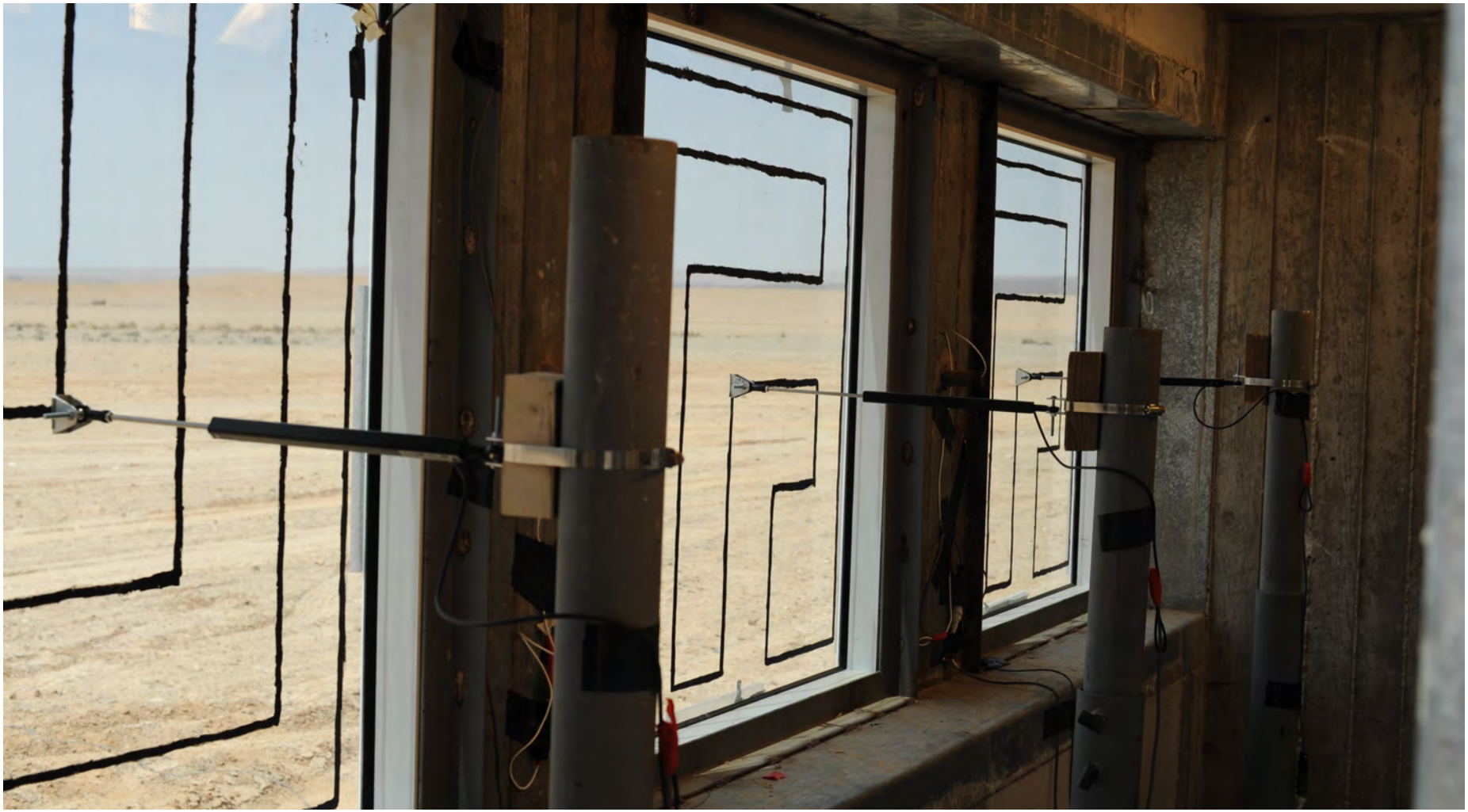
von Mises Stress-Time Distribution (Hollow)



Glazing Targets Before Test

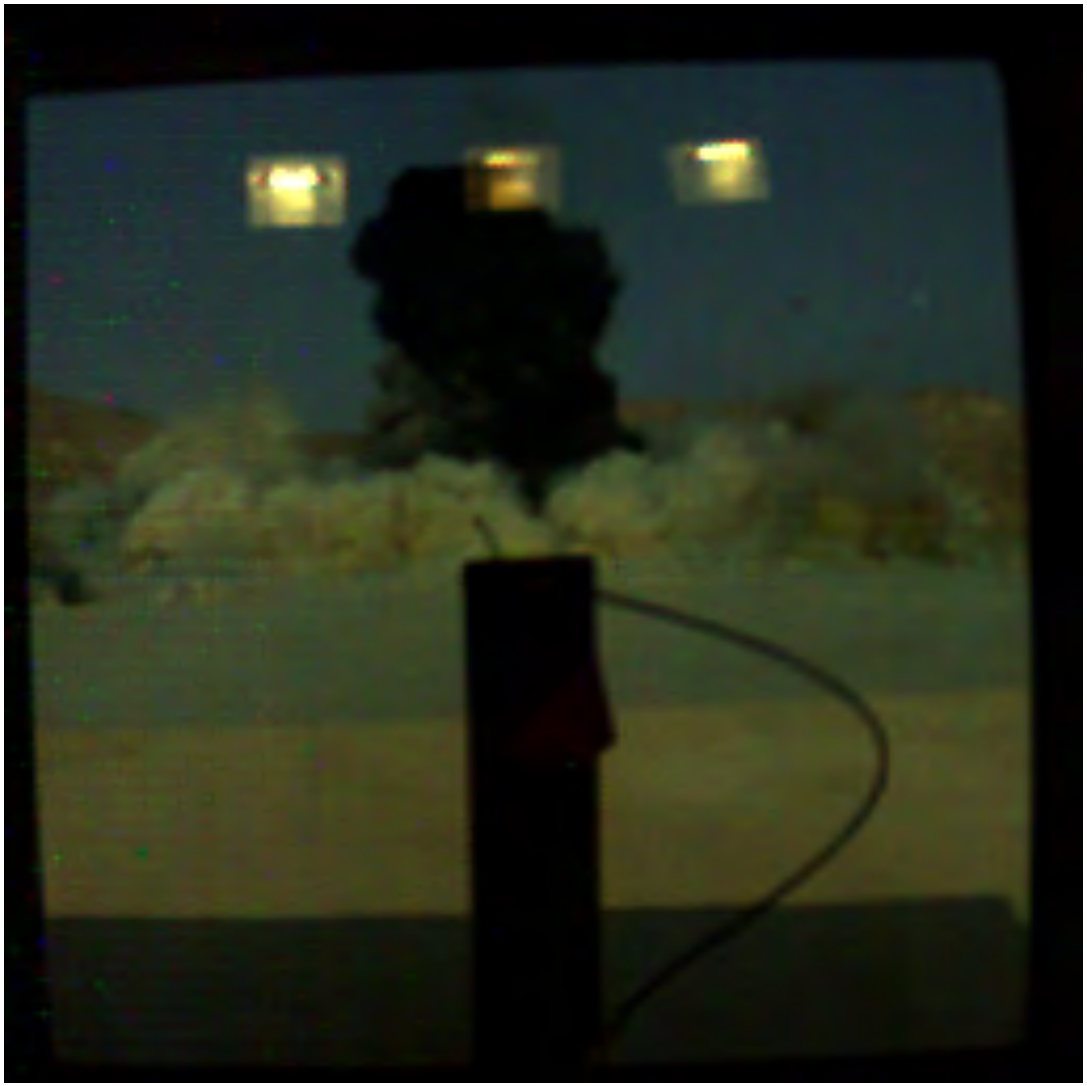
Glazing Targets Before Test

Glazing Targets Before Test



Glazing Detonation

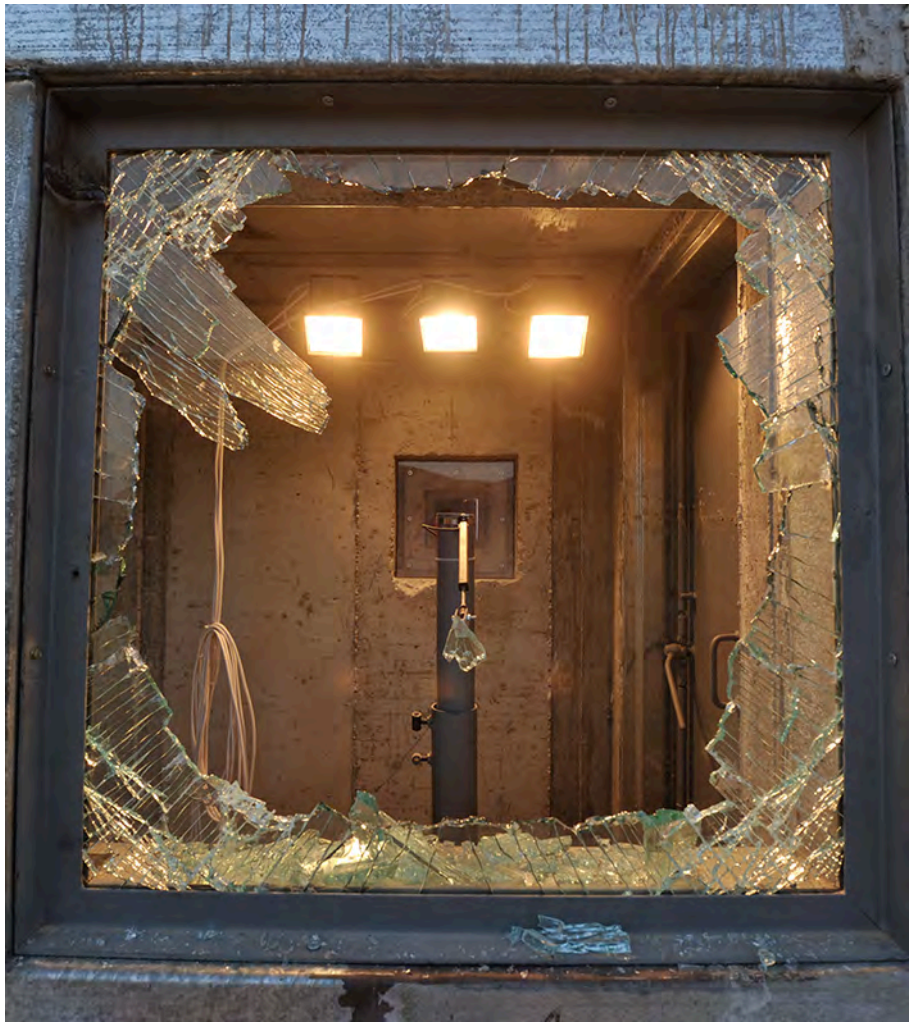
Pane Oscillations



Pane Failure

Glazing Target After Test

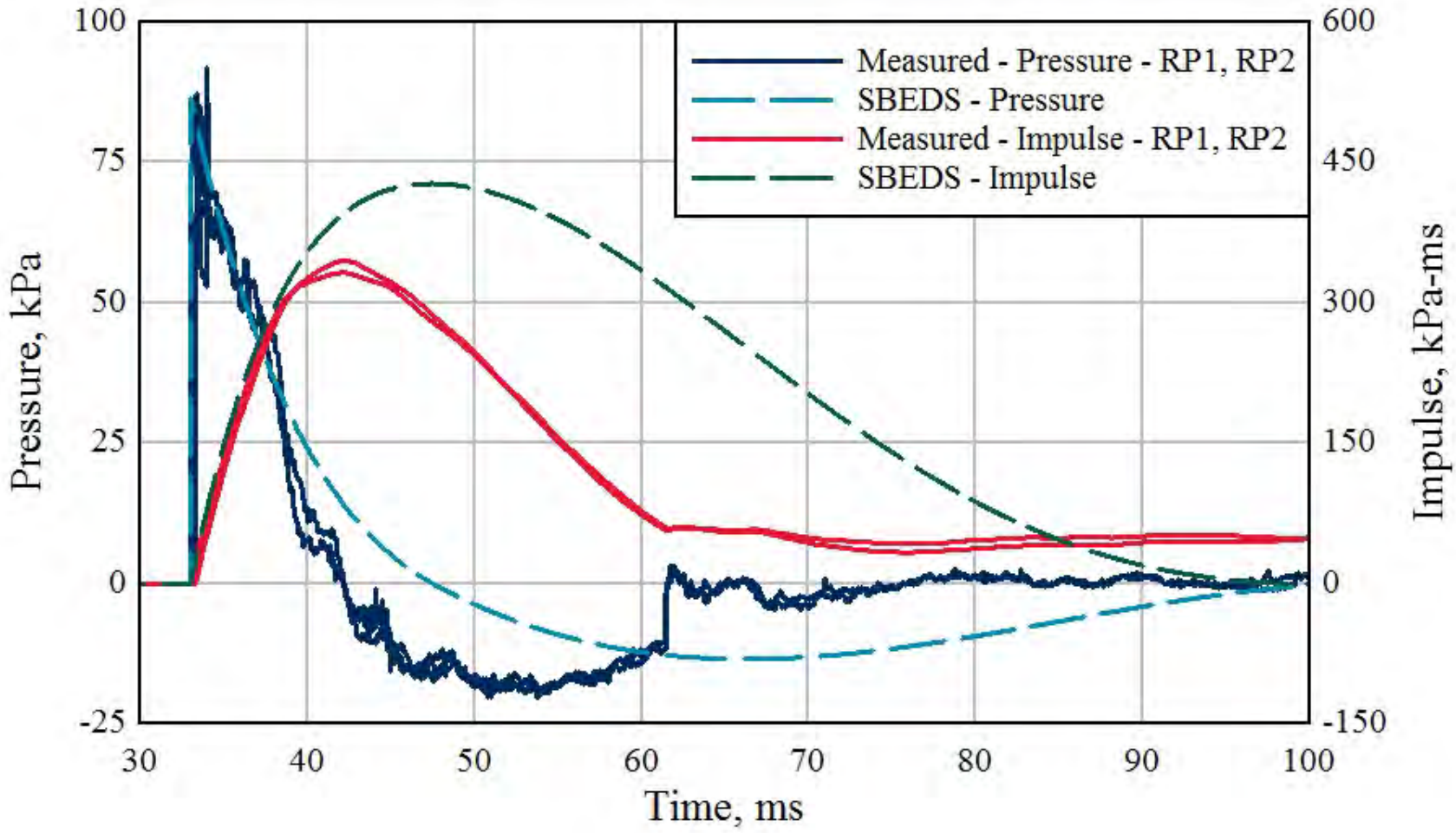
Glazing Target After Test



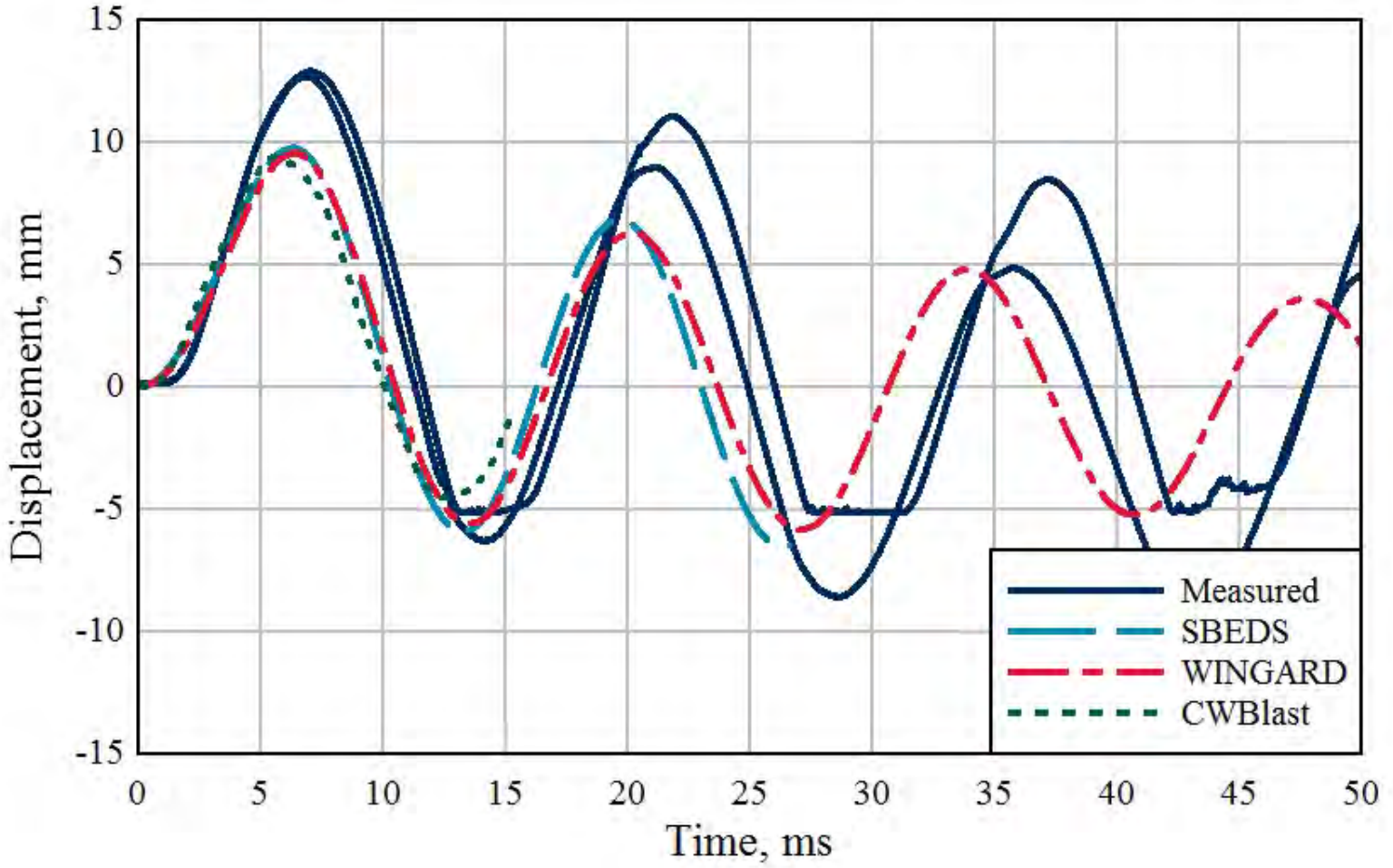
crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

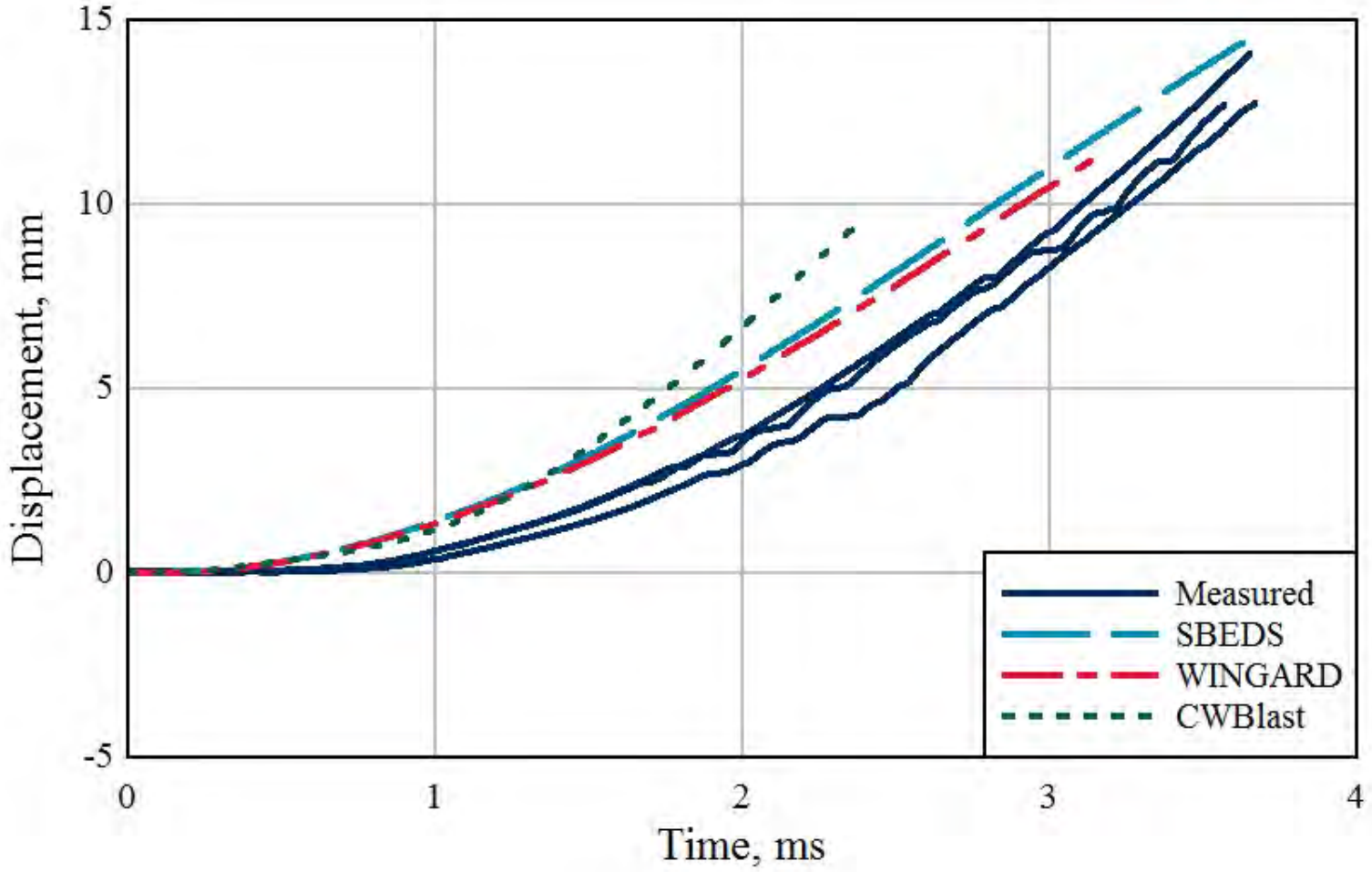
Glazing Reflected Pressure-Time History



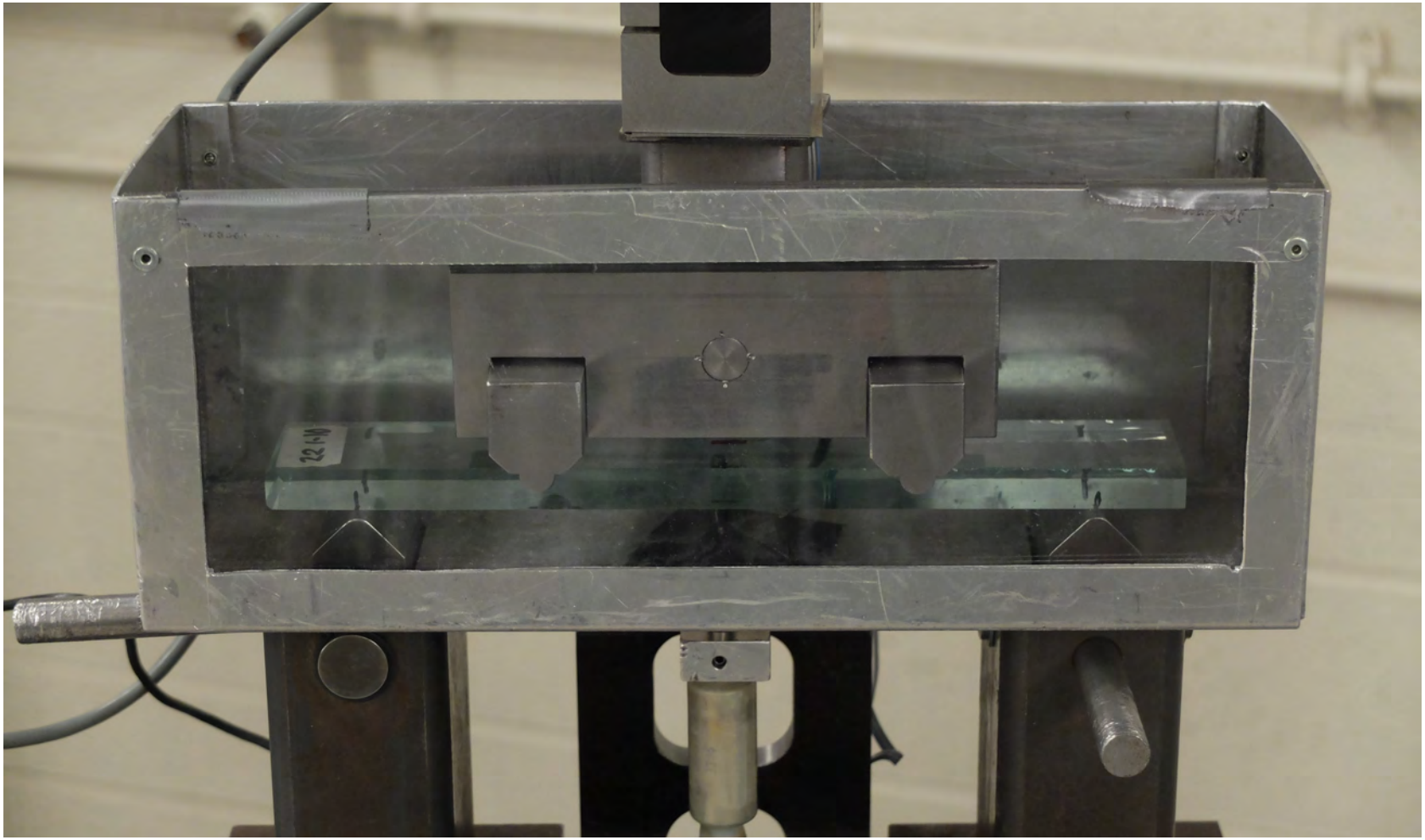
2012 Glazing Displacement-Time History



2013 Glazing Displacement-Time History



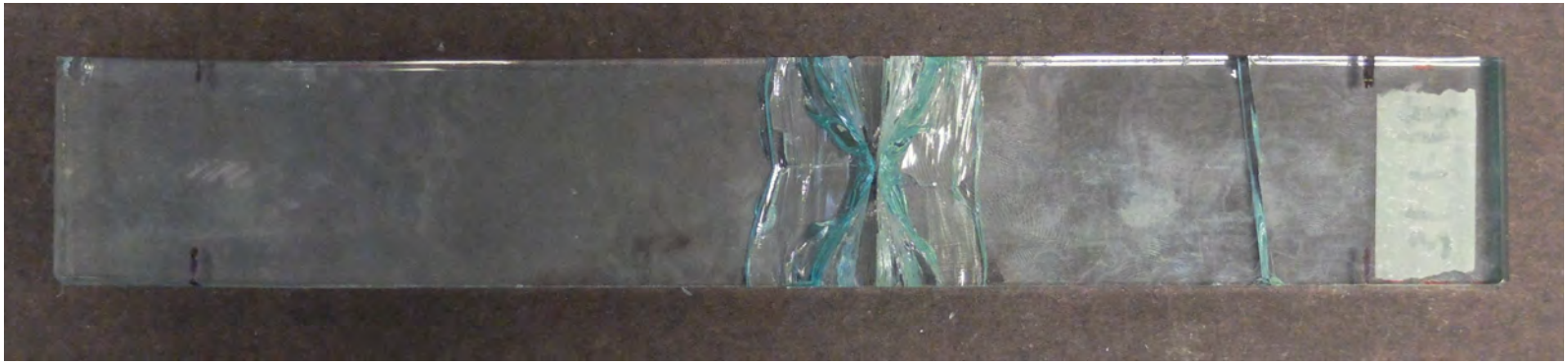
Four-Point Bending Test Apparatus



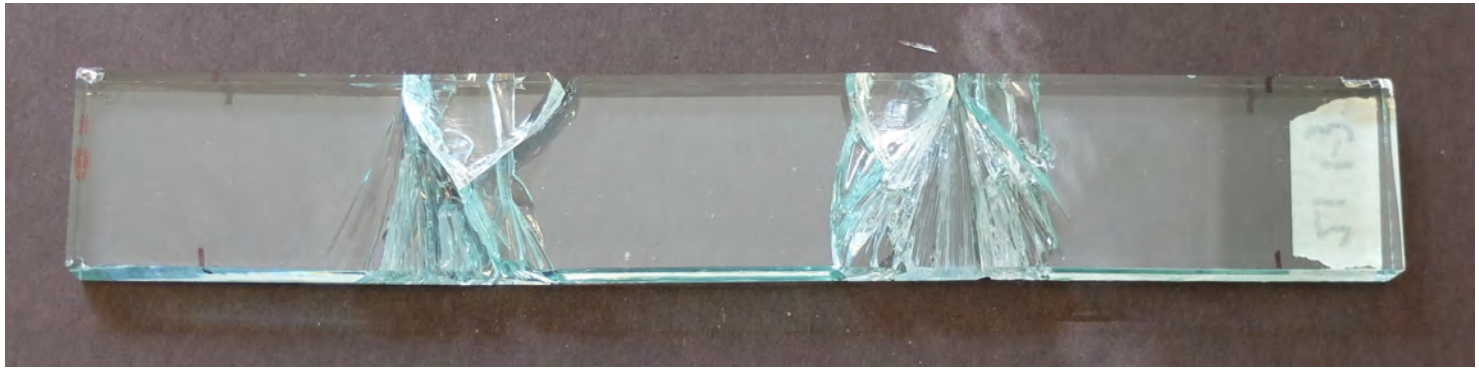
crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

Typical Failed Specimens



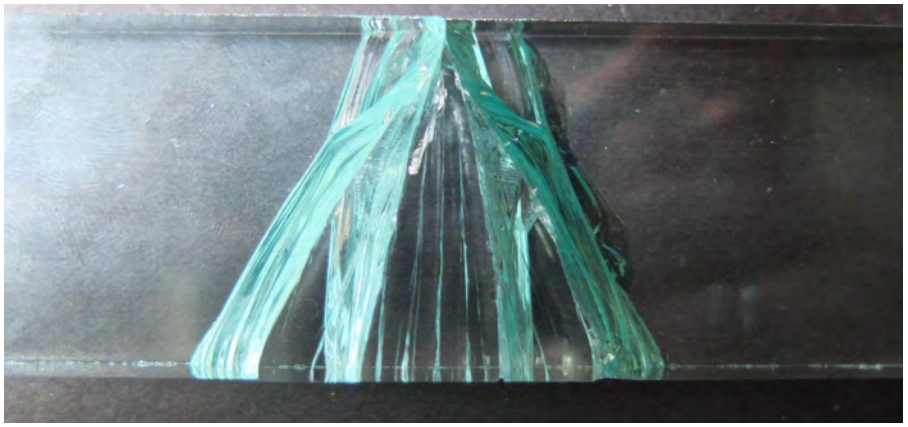
Failure Between Loading Points



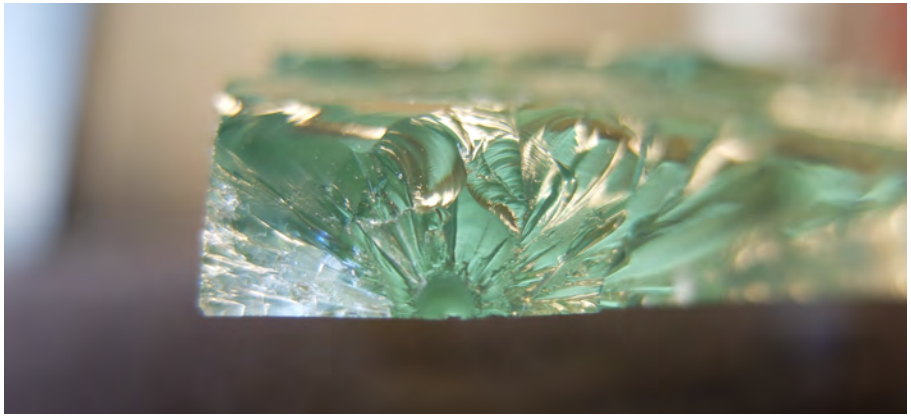
Multiple Failures at Loading Points

Static Failure Types

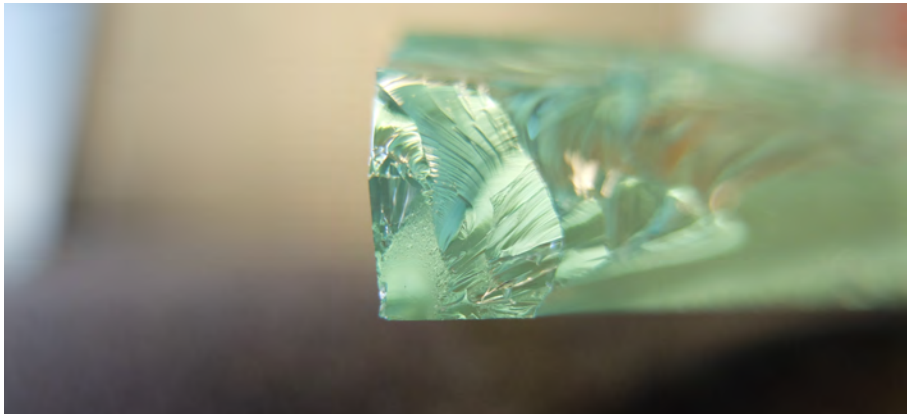
Face Failure – Plan View



Edge Failure - Plan view

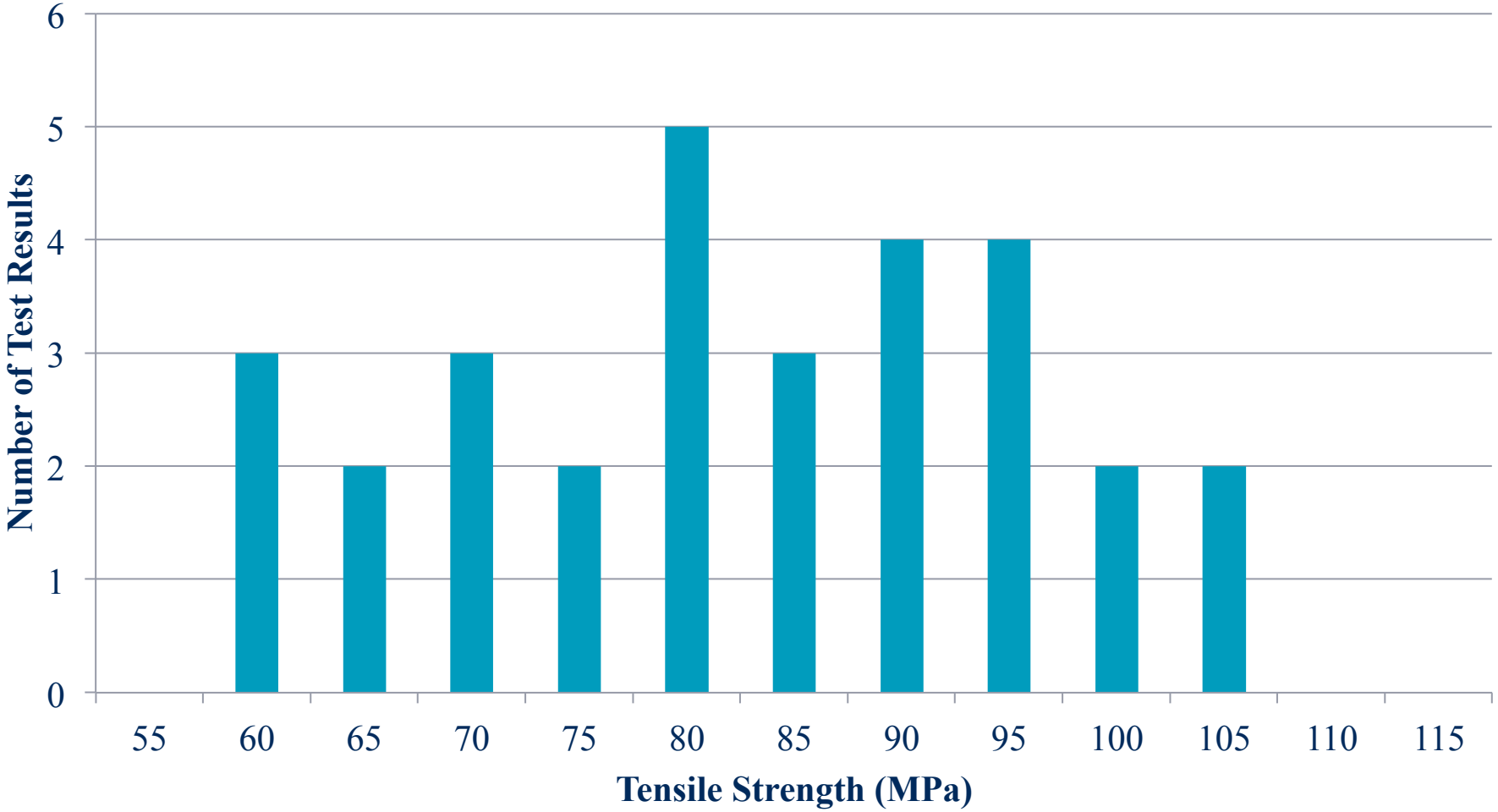


Face Failure – Cross Section

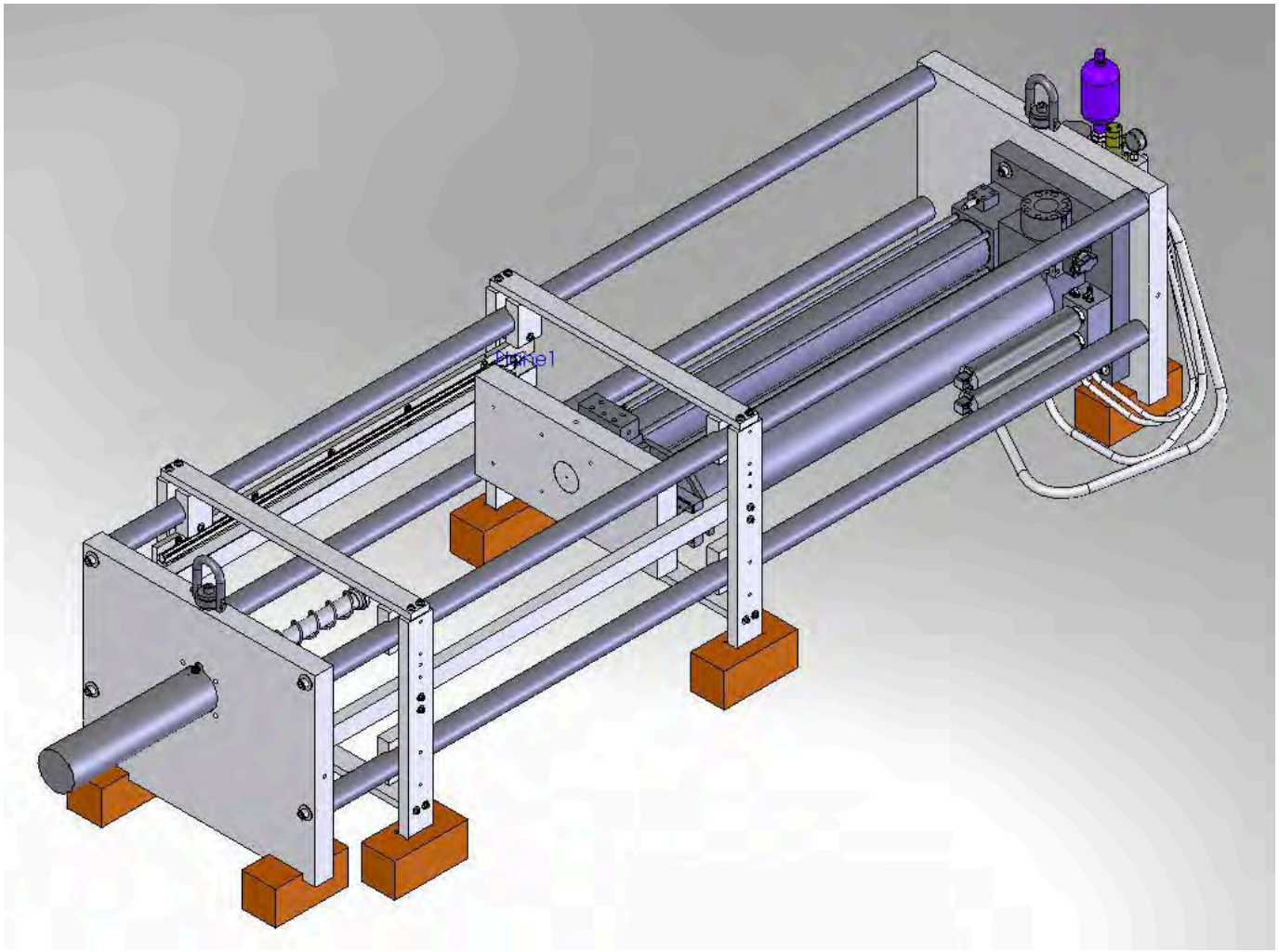


Edge Failure – Cross Section

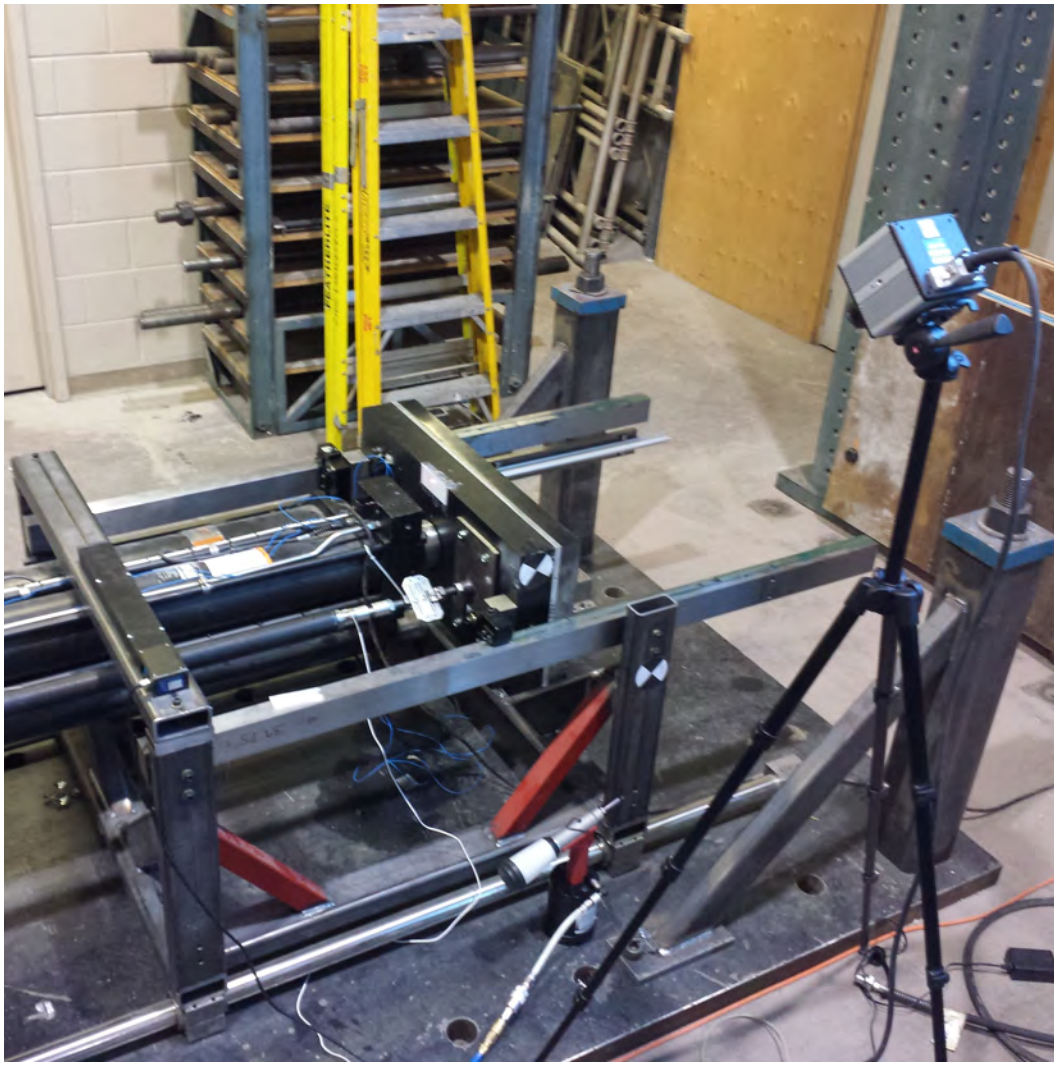
Distribution of Tensile Strength Values



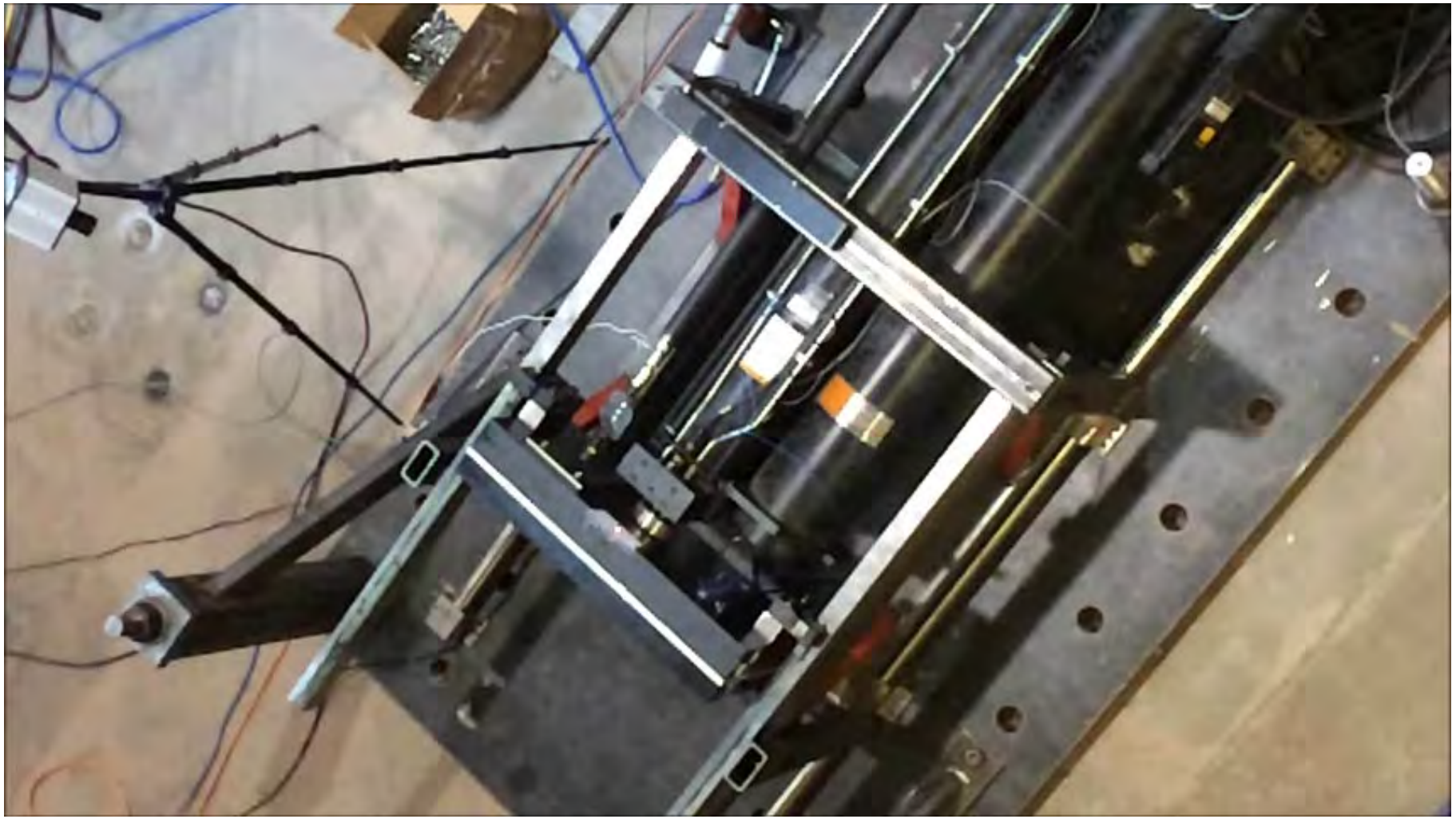
Blast Simulator



Laboratory Blast Simulator



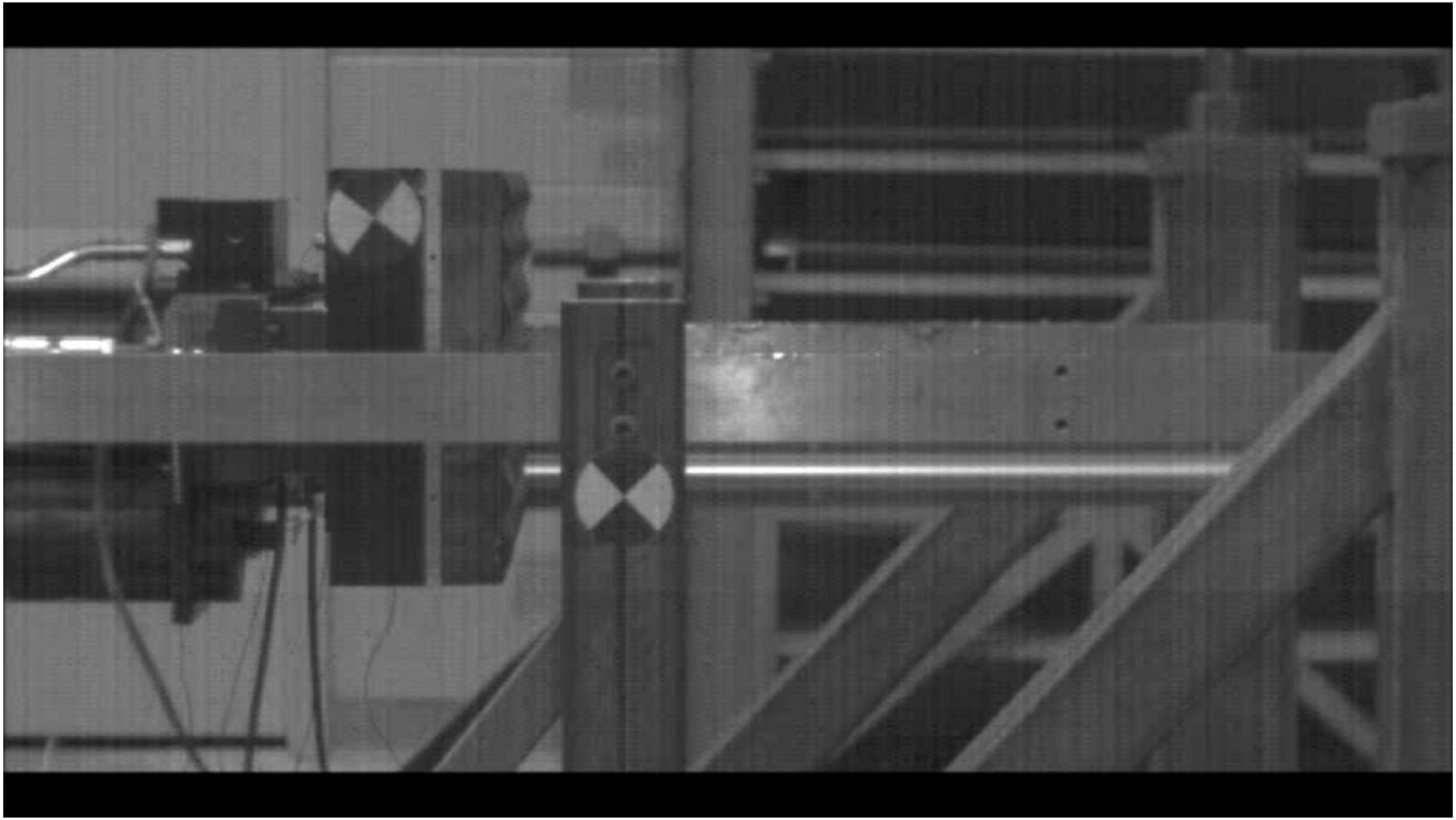
Laboratory Blast Simulator



crci | The Centre for Resilience of Critical Infrastructure

EPLORA FOUNDATION

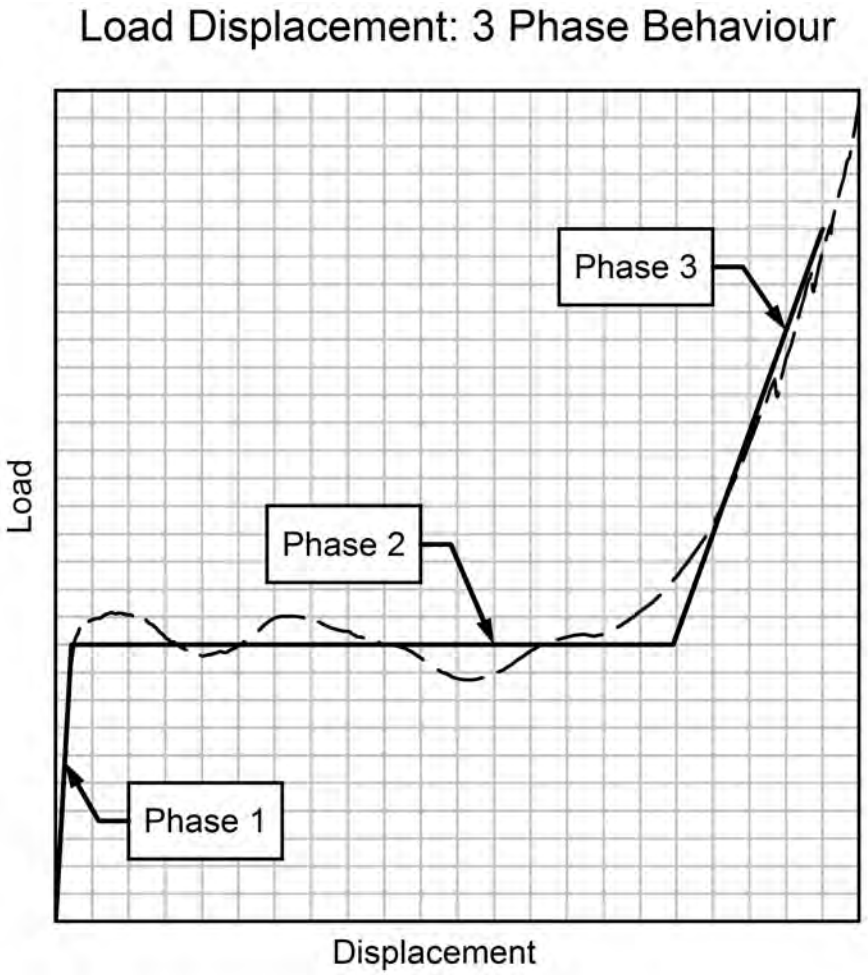
Laboratory Blast Simulator



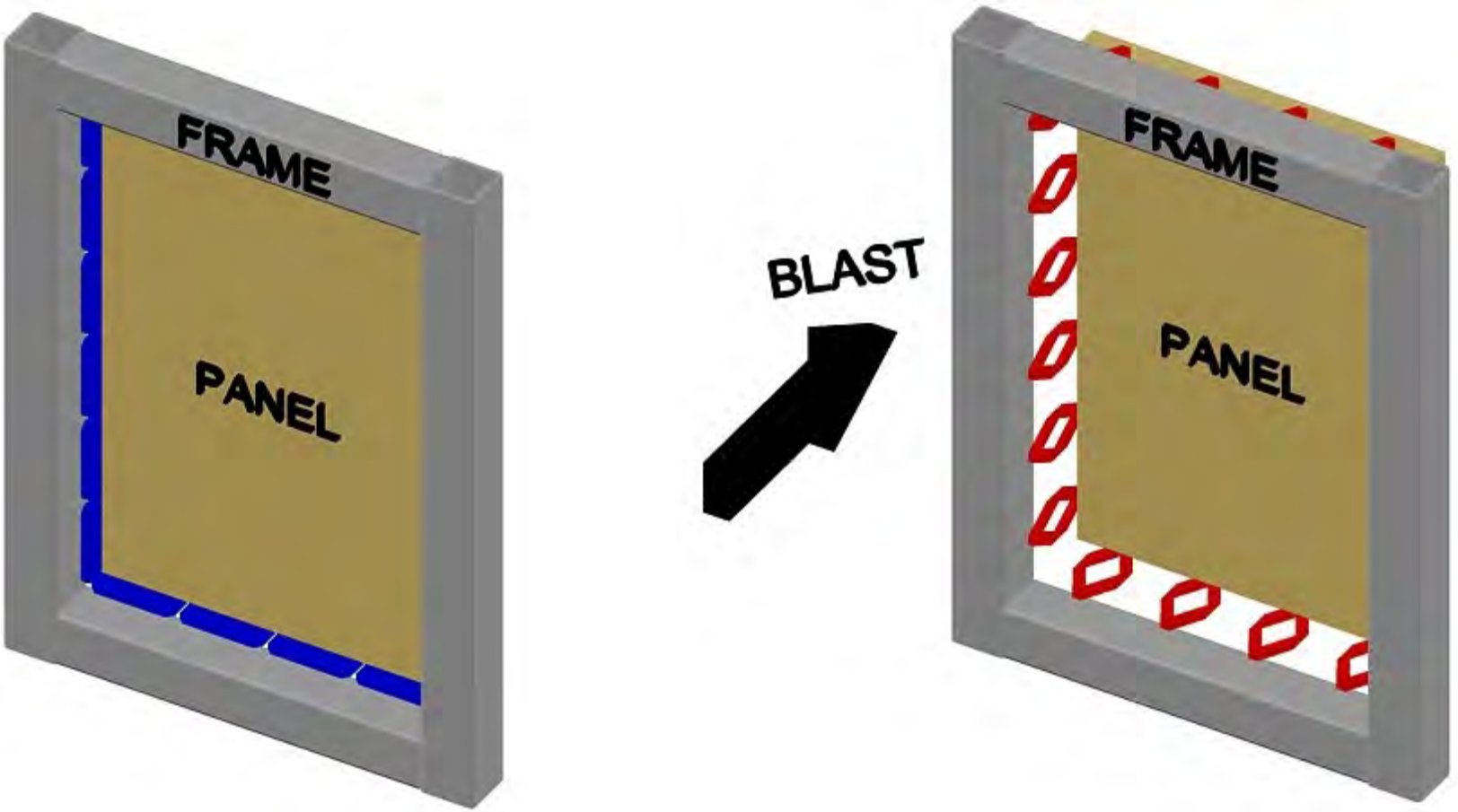
crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

Load-Displacement Curve



Future Blast Simulator Tests



Future Research

- 2015 Arena Field Blast Tests
  - Glazing, steel, etc.
- Laboratory experimentation and analytical work
    - Glazing, Steel
    - Blast Simulator
    - Numerical modelling and software development (e.g. CWBlast)
- Excellent Research Group
  - One Post-Doctoral Fellow, Two Ph.D. and Three M.A.Sc. Candidates
- Explora Foundation

Outreach

- Publications
  - Technical Journal Articles
  - Explora Foundation Blast Test Reports
- Presentations
    - Conferences, e.g. ISIEMS, MABS
    - Other groups
- Technology transfer to industry
- Education

Acknowledgements

- Explora Foundation
- NSERC, OGS and other governmental organizations
- Prof. Jeff Packer
- Research Group
  - Min Sun, Cameron Ritchie, Kevin Spiller, Matthew Gow, Kyle Tousignant
- Prof. David Yankelevsky
- Many others…

crci | The Centre for Resilience of Critical Infrastructure

EXPLORA FOUNDATION

#CRCISFF

www.crci.utoronto.ca