Phasing out of Conventional Ductile Seismic Design: An overview of research toward a next generation of seismic resistant structures

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Geleceği Güçlendirin!

Christchurch, 2011
minutes after M6.3 earthquake

- **Limited number of deaths (most in one poorly designed building)**
- But, more than $30 Billion in losses
- 80% of the tallest 50 buildings in Christchurch have or will be demolished even though they met their design goal or preserving life during a design level earthquake.
- Estimated that it will take at least two decades to recover fully

Ductile Design =
Damage to main structural elements through inelastic yielding and residual deformations

Can Lead to total Loss of Buildings even if they respond as expected and as intended by current modern seismic codes

Armagh & Oxford, 5pm

14-storey Building in Sendai-City

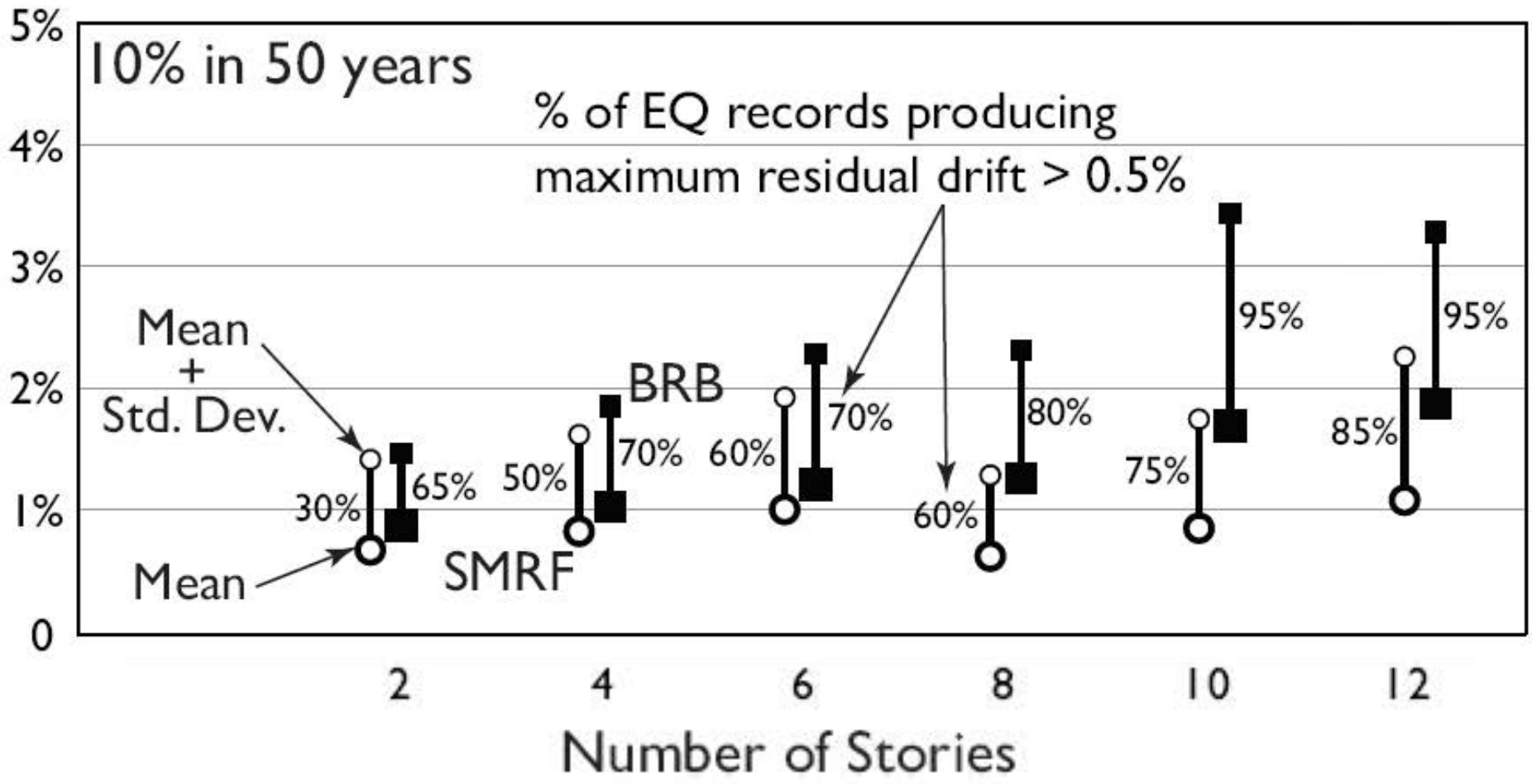
Possible Practical Limits for Residual Drifts

- Permissible out of plumb for new construction = 0.2 % drift
- Re-alignment most likely required for residual drifts greater than 0.5%
- Total loss of structure if residual drift is of the order of 1% or greater

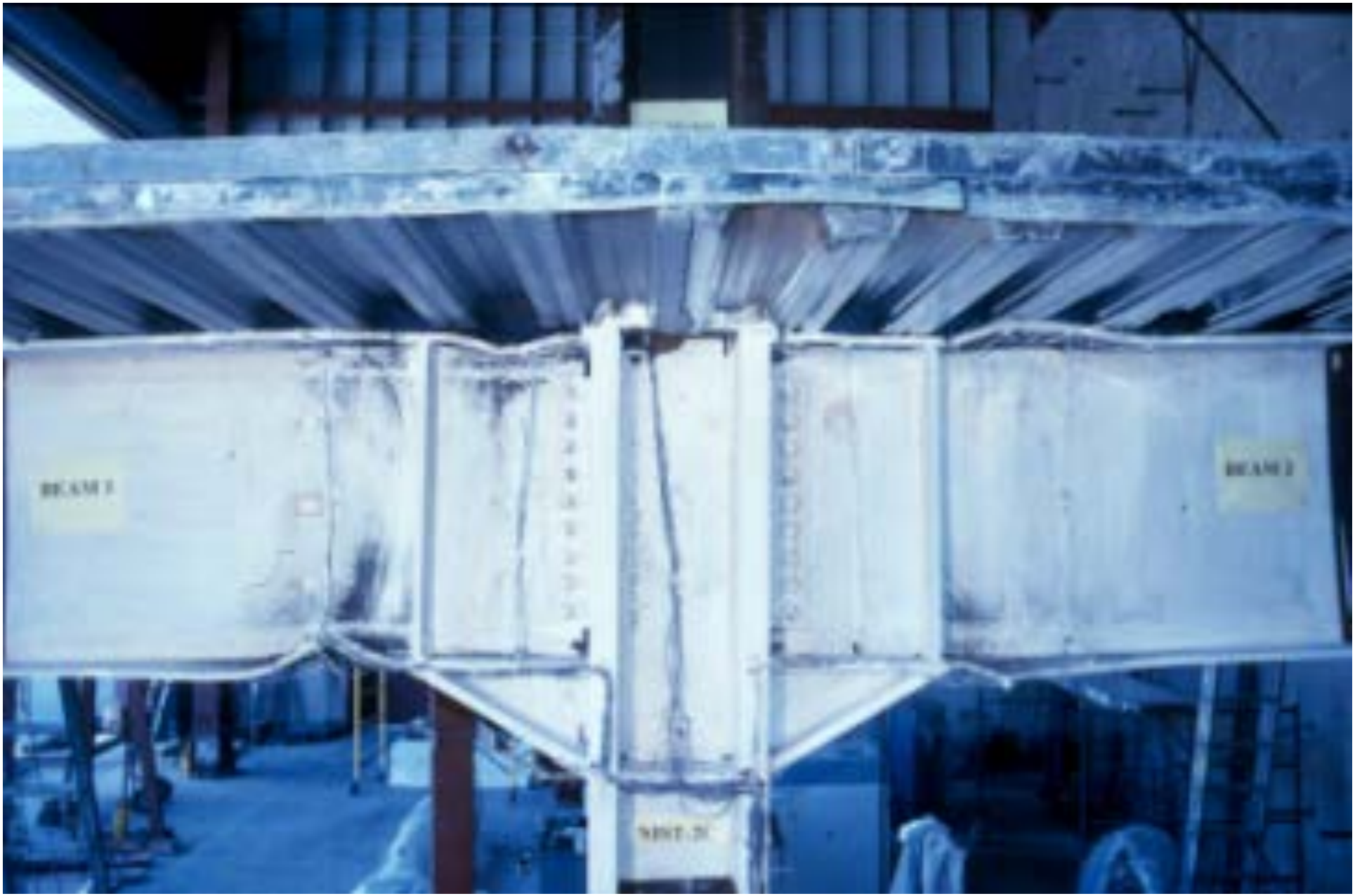
McCormick et al. (2008) – Study done on real buildings with post earthquake residual deformations ---- *concluded that in Japan less expensive to rebuild a structure than to repair it when residual drifts greater than 0.5%.*

Residual Deformations of Steel Structures designed according to ASCE-7 (05)

Erochko et al, 2010 – ASCE Journal of Structural Engineering



Results from 20 Spectrum Compatible Records


BEAM 1
BEAM 2

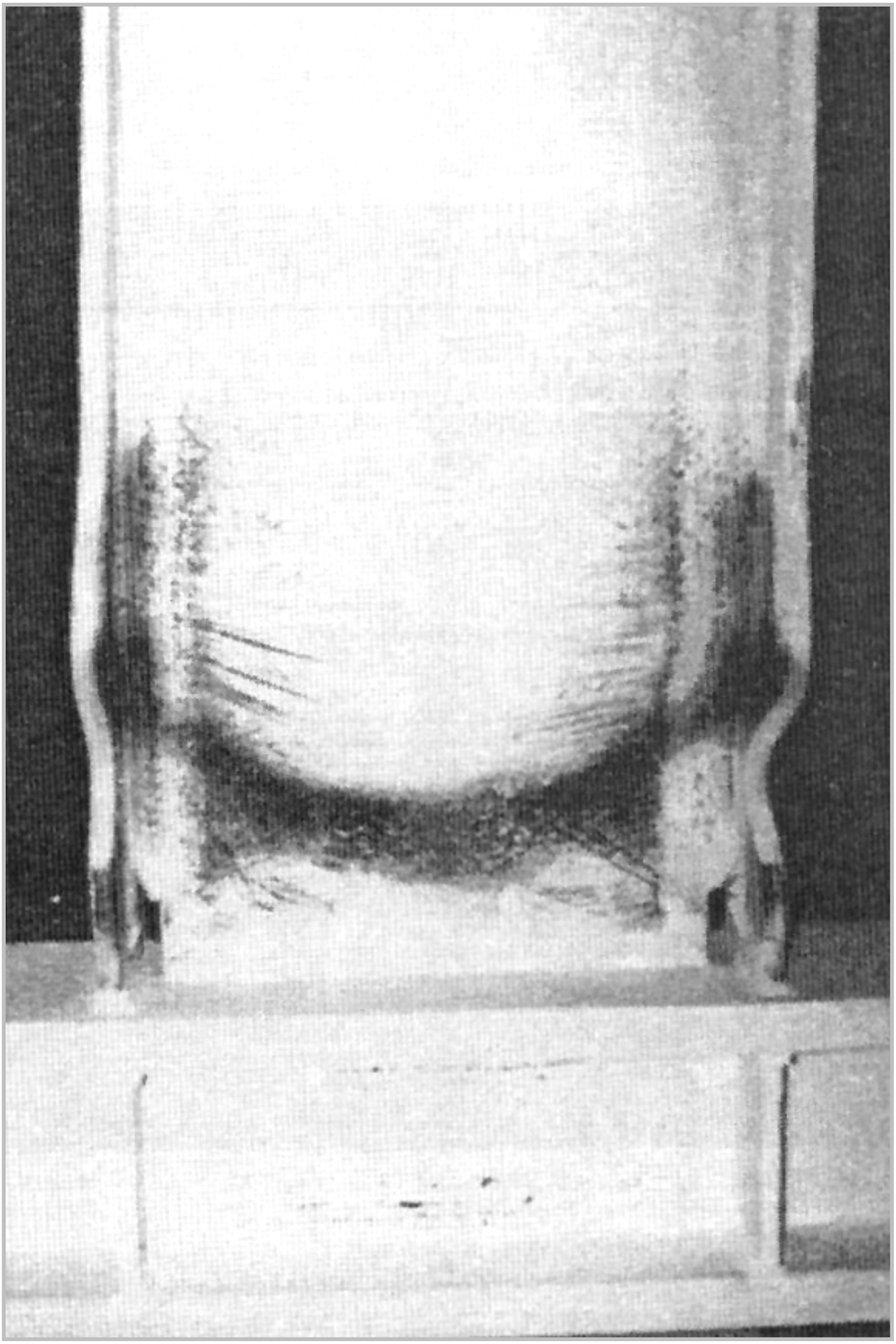
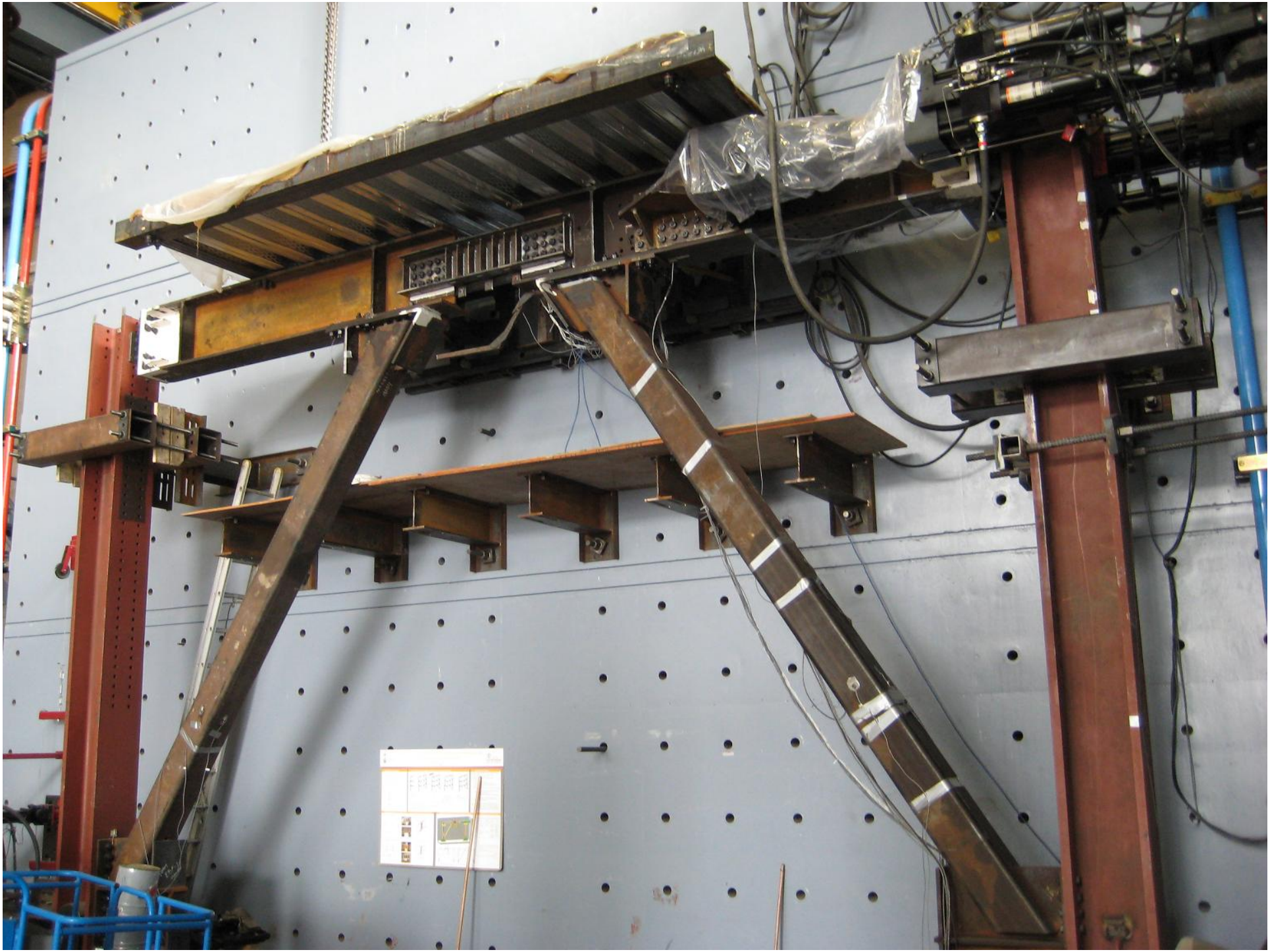


Photo 3

Photo 4

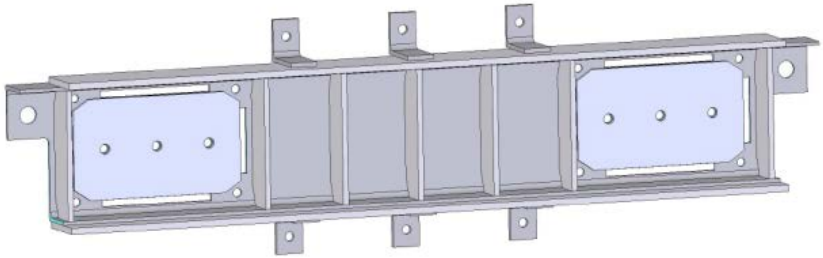
Some research towards the development of resilient seismic-resistant systems in Canada

- ***Steel frames (MRF and EBF) with replaceable nonlinear links***
- ***Braces with Yielding Connectors***
- ***Self-Centering Bracing (SCED) Systems***
- ***Base Rocking Steel frame systems (with higher mode control)***
- ***Damped Coupling Beams for high-rise buildings***

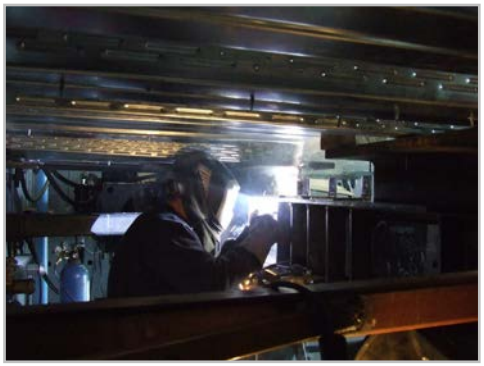


Welding Replacement Technique

Steel Deck in place to simulate accessibility constraints during replacement – repair carried out with 0.5% residual drift imposed on frame



Replacement Welded Link

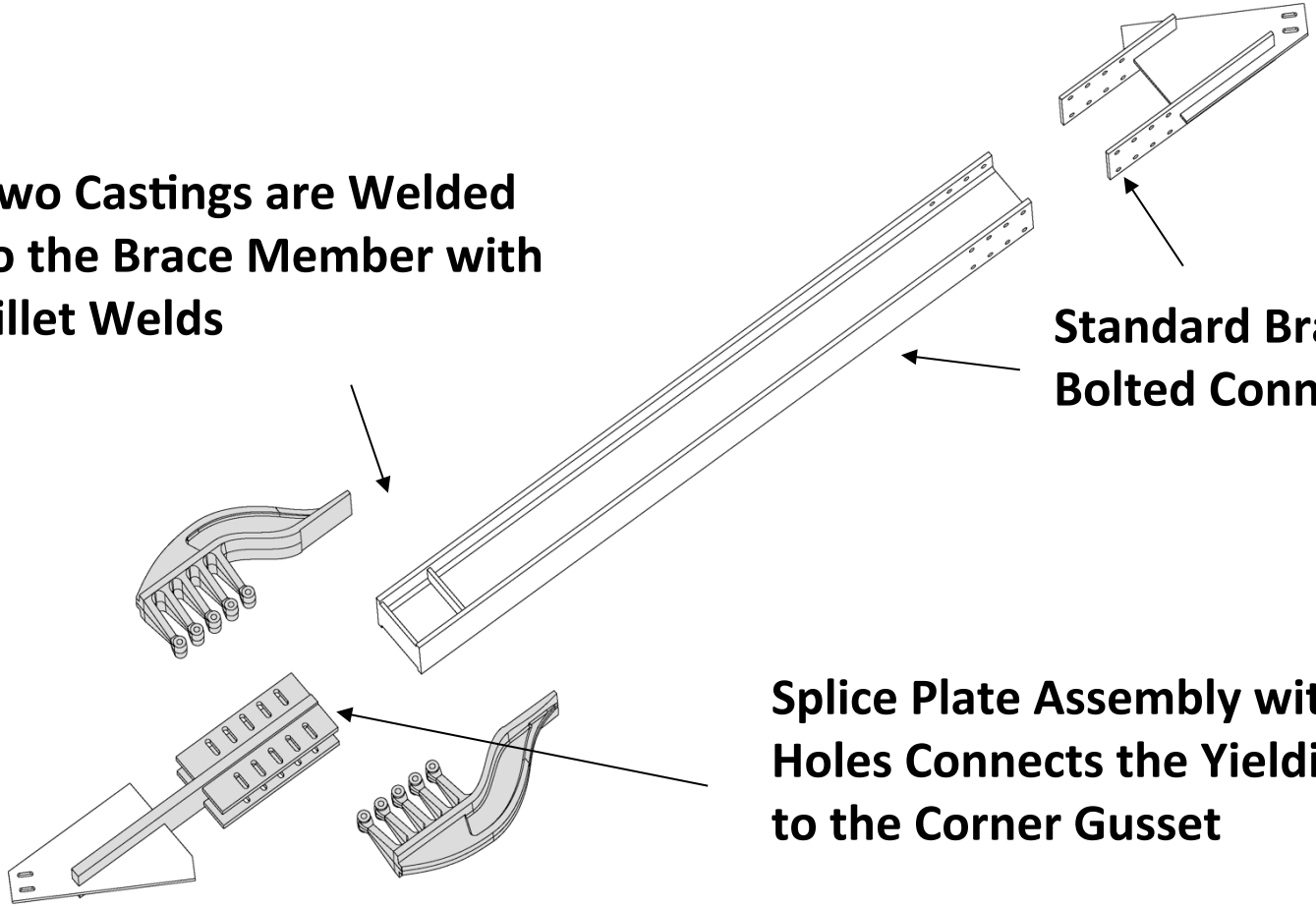


Welding on site

Recent Implementations of replaceable EBF fuses in Christchurch, NZ

Now Codified in CSA-S16 (2014) Canadian Steel Code

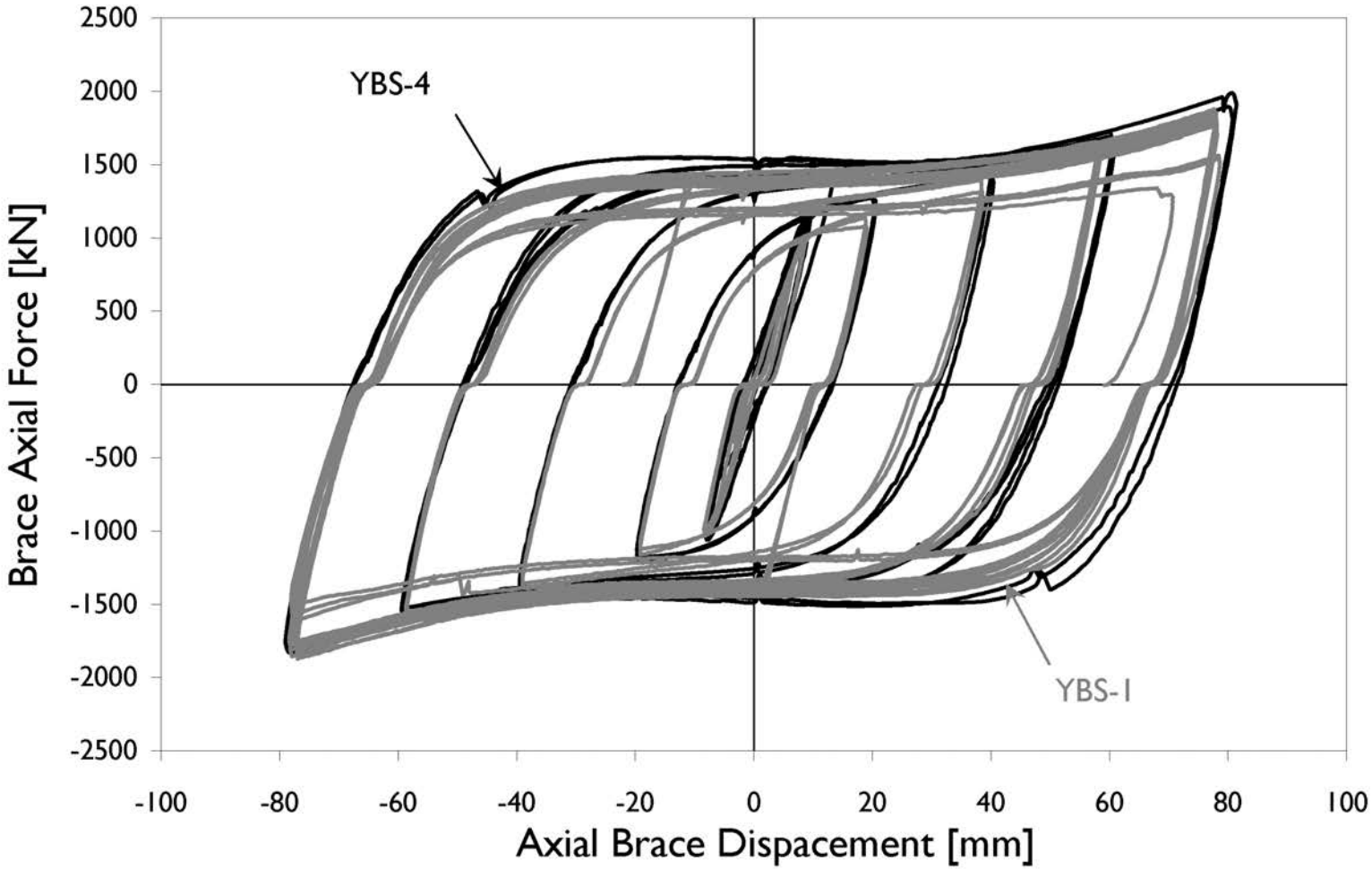
Brace Equipped with Yielding Connector



Connector and brace combine in series to give stiffness allowing for independent control of stiffness and yield load (by changing brace section but or connector)

Repeatability of Castings

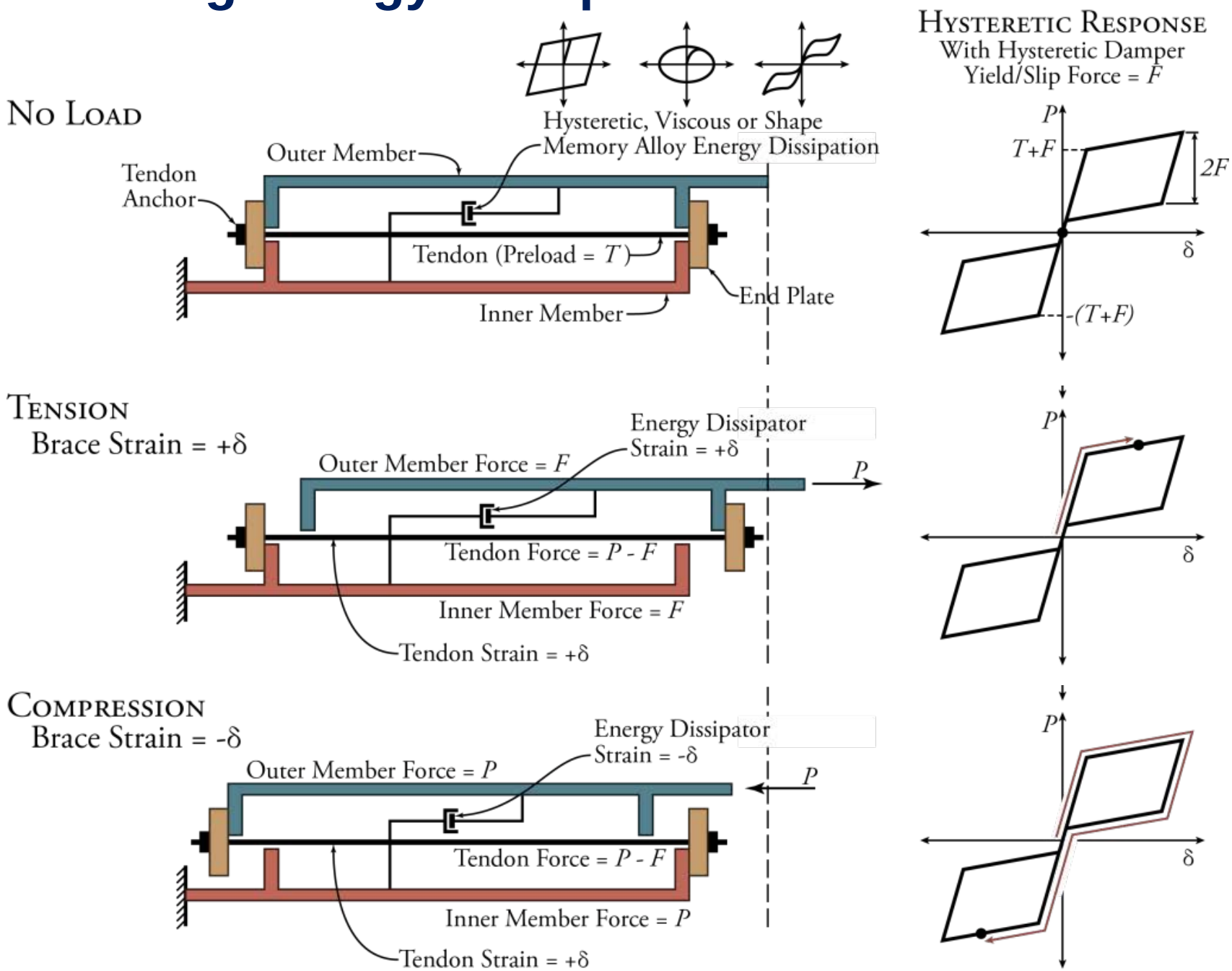
YBS-1 and YBS-4 Were Manufactured 8 Months Apart

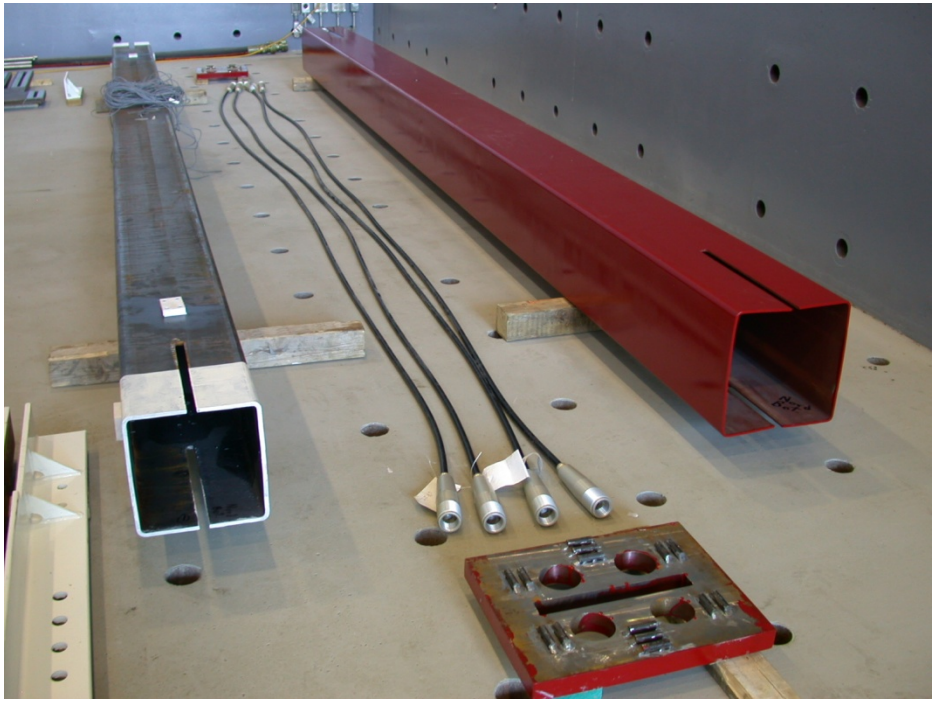


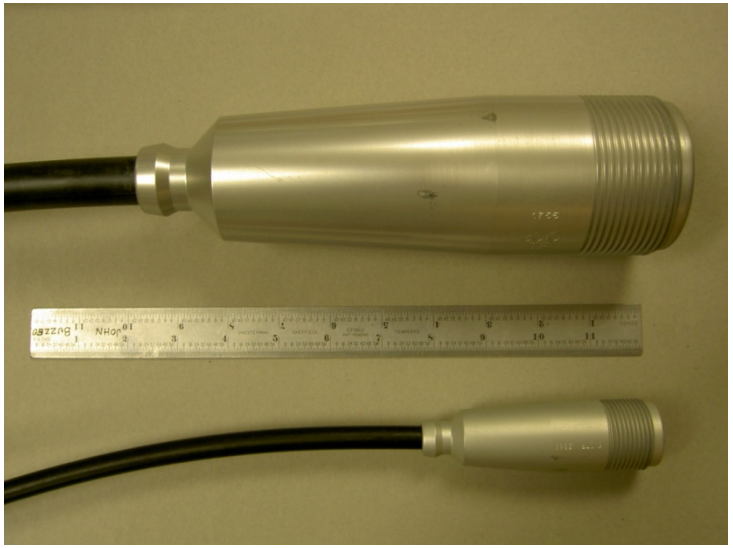
Whistler, British Columbia

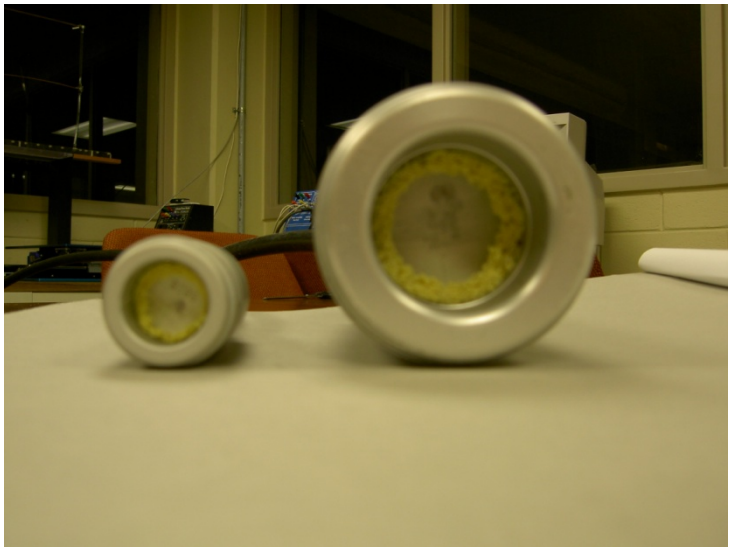

United Rentals
United Rentals

Self-Centering Energy Dissipative Brace

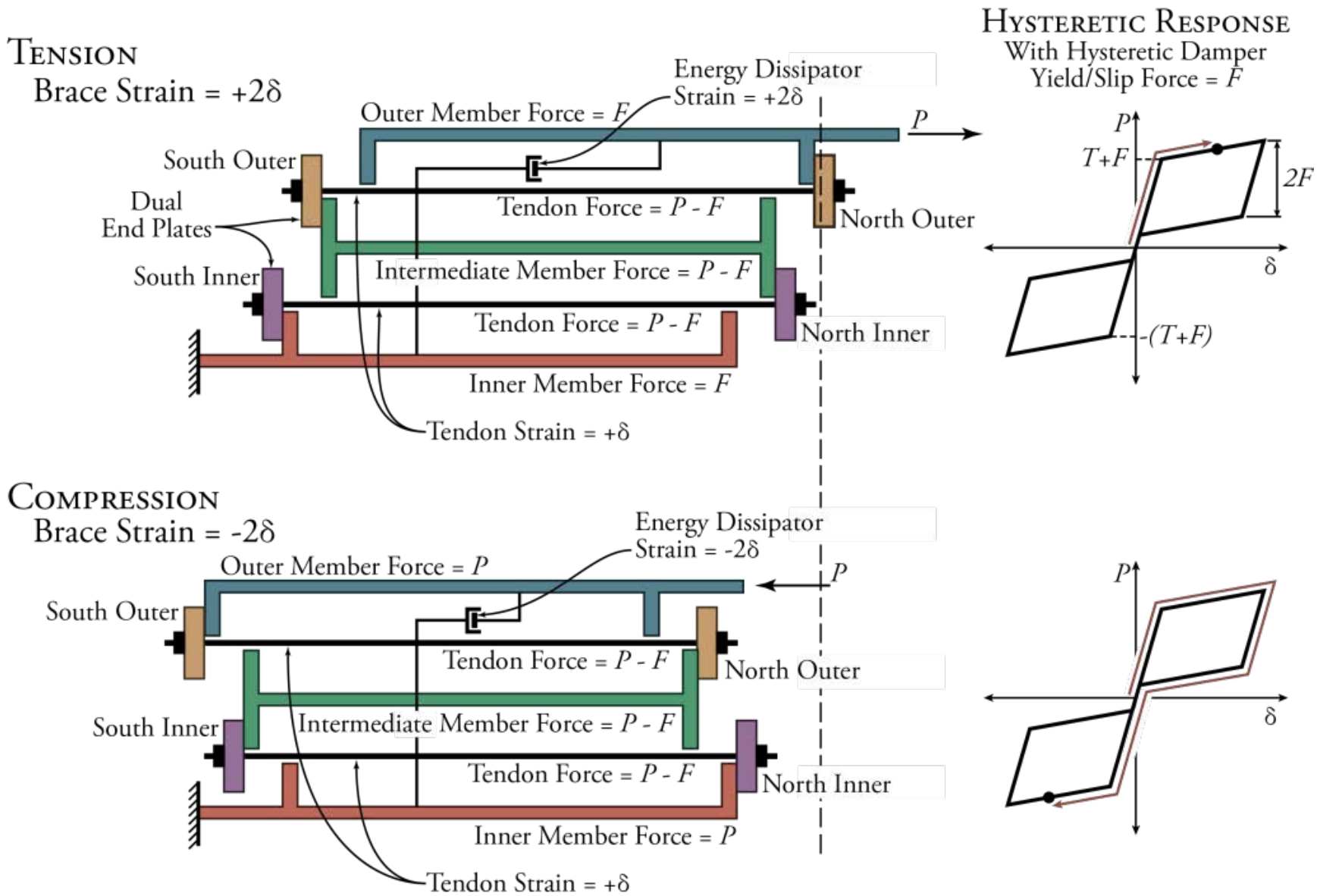








Telescoping SCED Brace (T-SCED Brace)

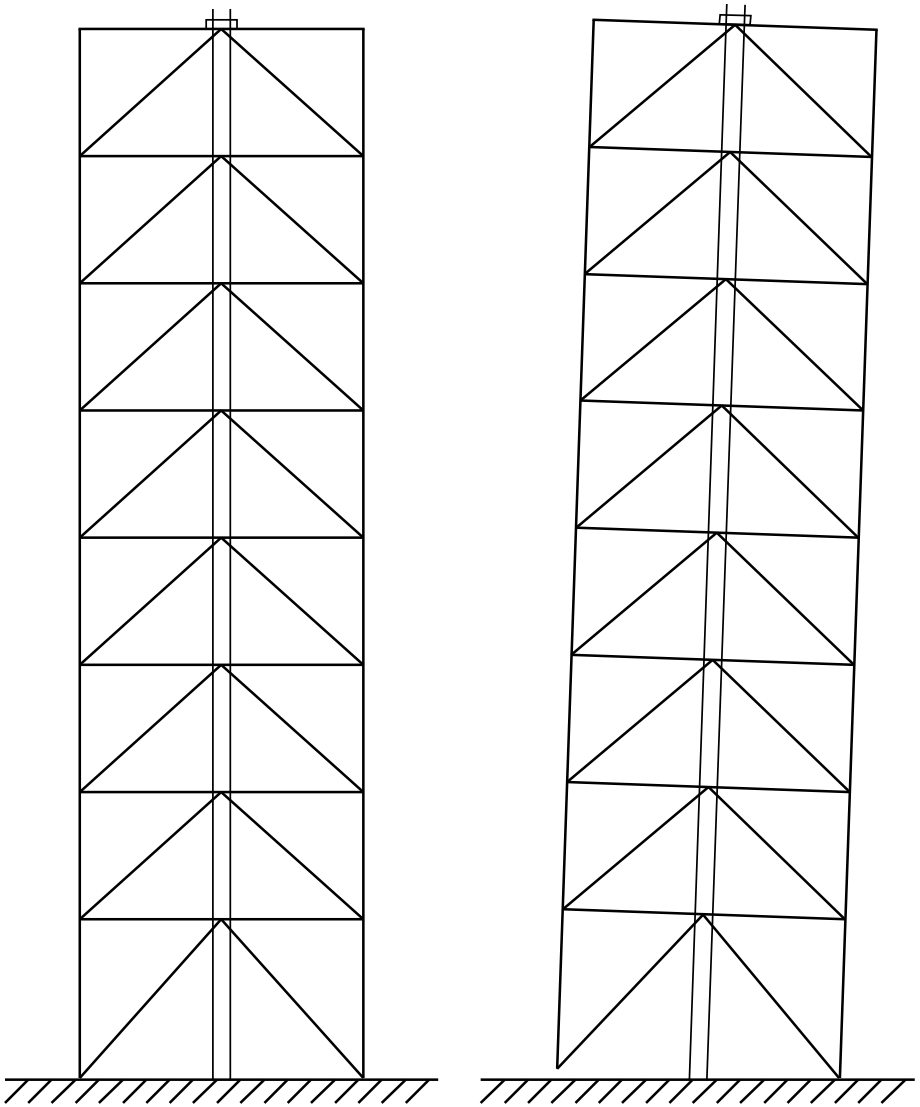


Self-Centering Base-Rocking Systems

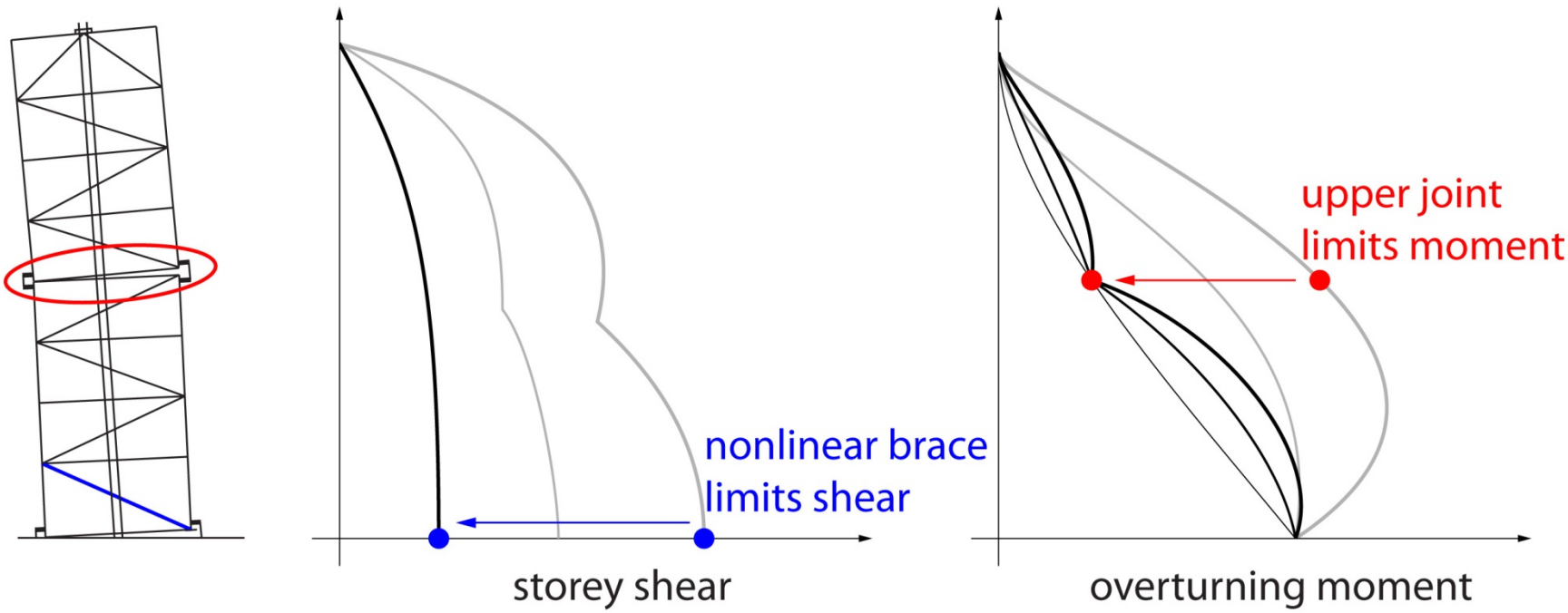
- Rocking of structures (unintended in the past) has allowed for many seismically deficient structures to survive earthquakes

- Primarily a result of deficient foundations that allowed structures to uplift

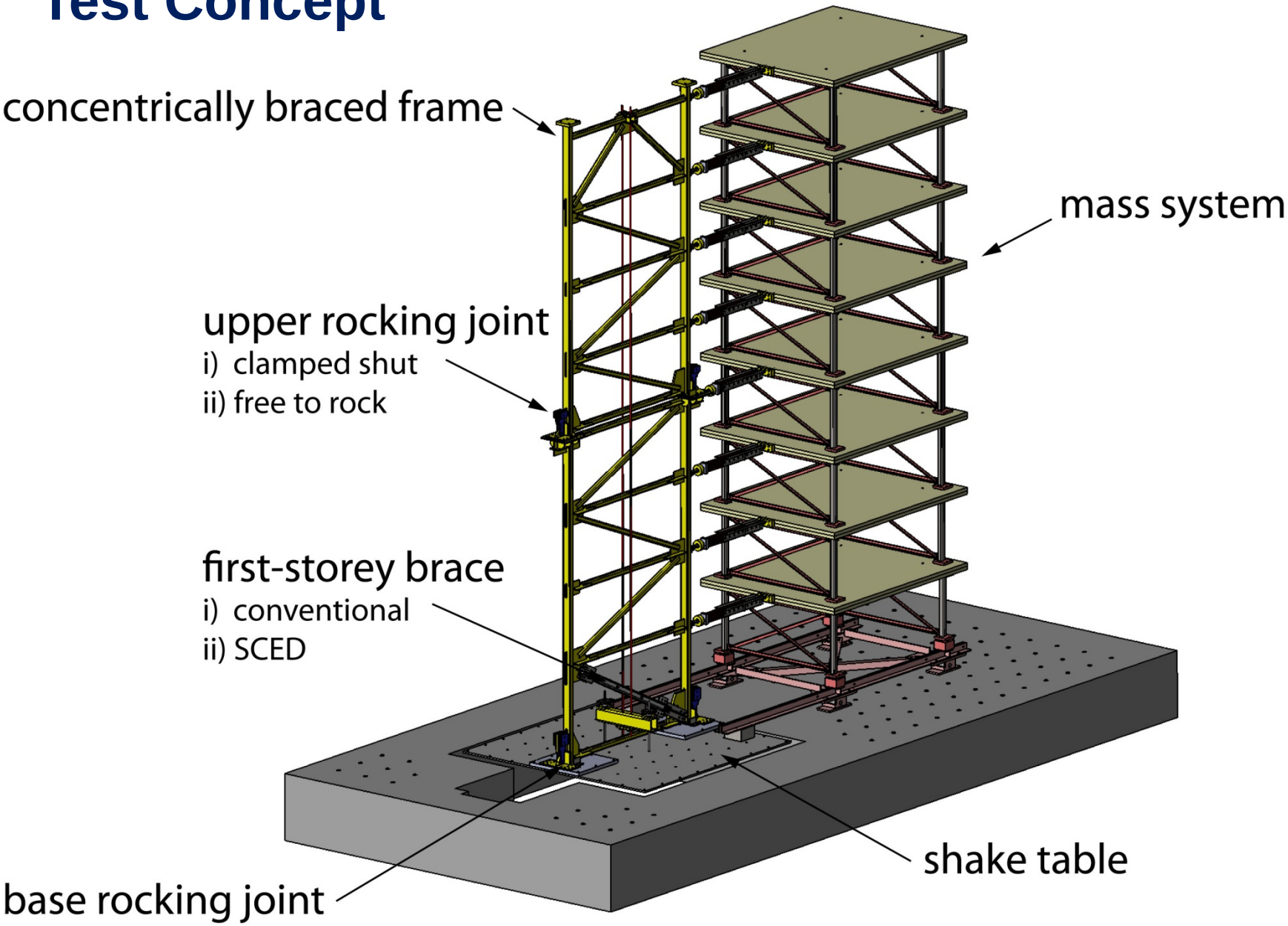
- Can be engineered as the intended response to provide self-centering undamaged seismic response



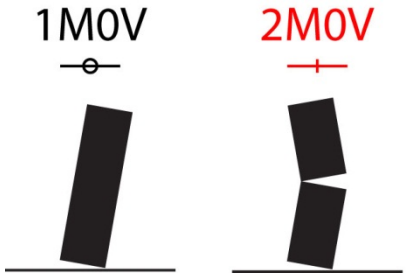
Rocking Structures with Engineered Higher Mode Control Systems

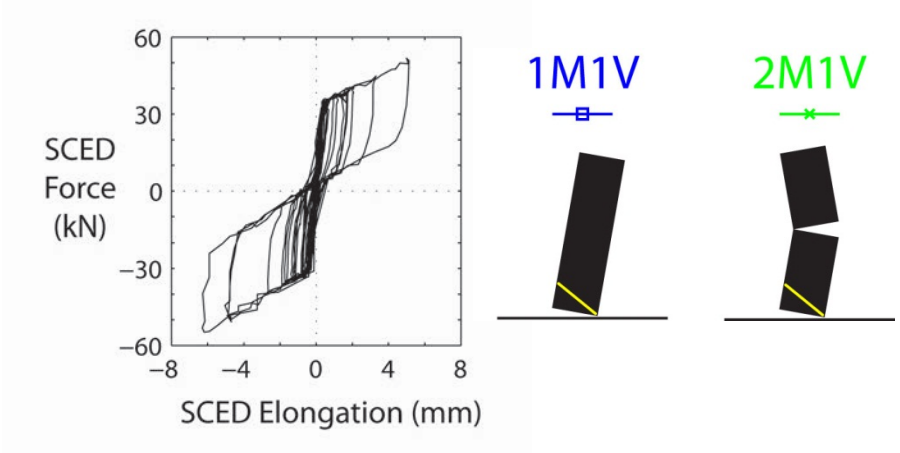


Test Concept



First-storey brace





Expected Seismic Performance

This building performed as designed according to Current National Building Codes

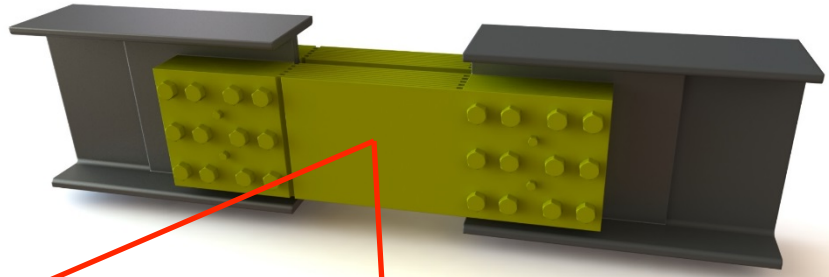
This building was decommissioned (LATBSDC 2010)

Walls

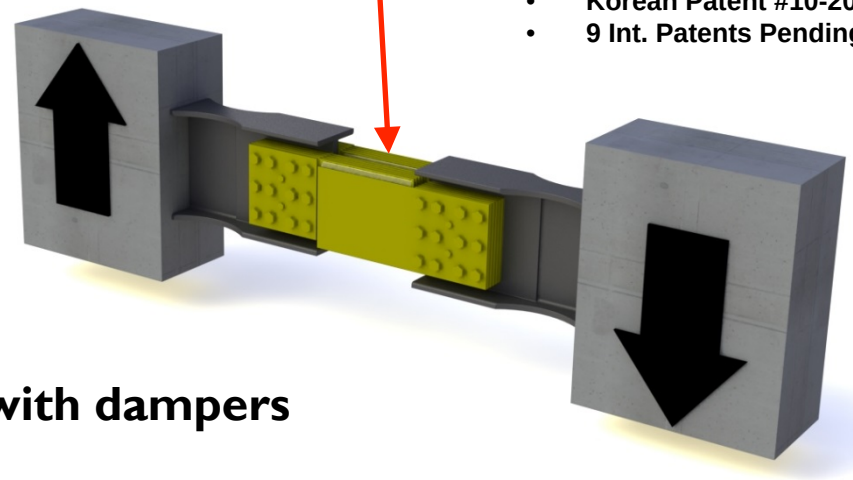
Beams

Viscoelastic Coupling Damper (VCD)

Developed at University of Toronto in collaboration with Yolles Partnership

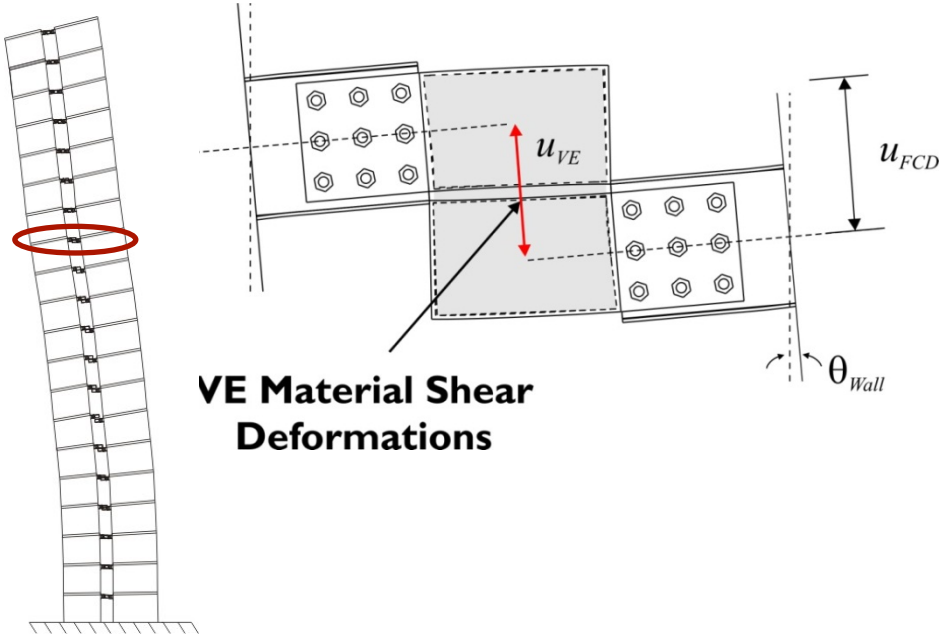


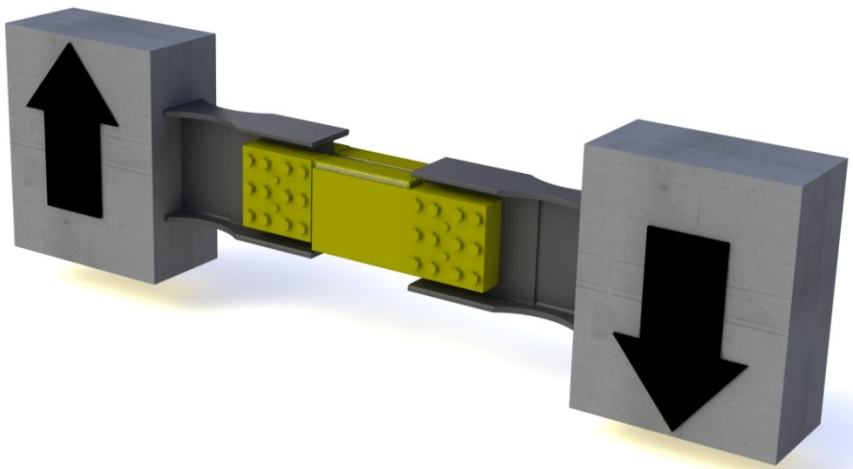
- US Patents #7,987,639, 8,516,753, 8,881,491
- Canadian Patents #2,634,641, 2,820,820
- Chinese Patent #200680040409.X
- Korean Patent #10-2008-701296
- 9 Int. Patents Pending



- **Replace** concrete link beams with dampers
- Multiple layers of **high damping Viscoelastic material (VE)** sandwiched between steel plates
- Adds distributed damping for **both wind and earthquakes**

Kinematics of Coupling Damper





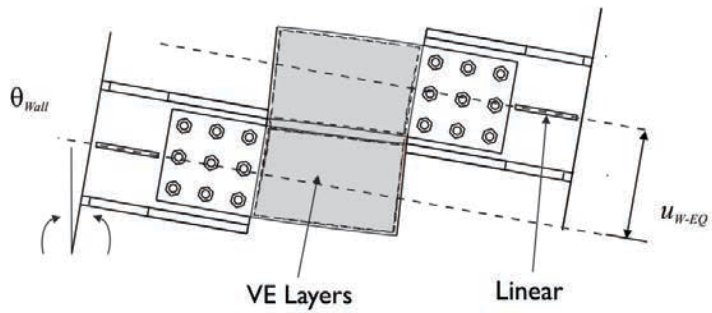
- Walls **rotate** about centerline causing **large shear deformations** in between ends of walls
- Coupling Damper VE Material undergoes **shear deformation**
- **Added Damping** (equivalent VE behavior) under **wind and DLE** events
- **Viscoelastic-plastic** behavior under **Maximum Credible Earthquakes**

Performance Based Wind and Seismic Design

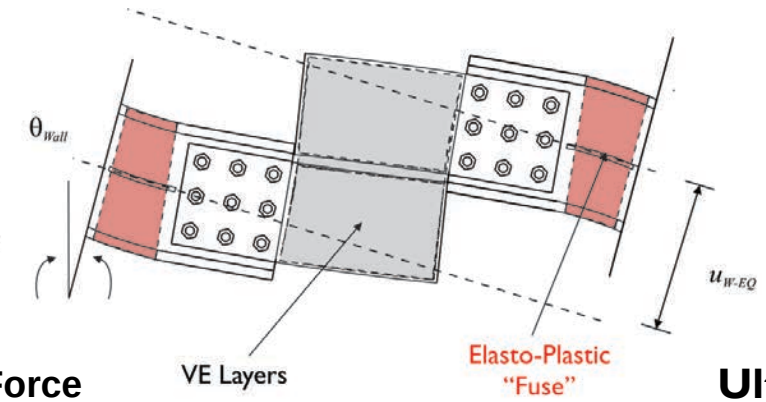
	All Wind Loads	Frequent / Design Level Earthquakes	Maximum Credible Earthquakes
VCD Performance Targets	**Added Damping** reduces: • Accelerations • Drifts • Velocities • Forces		**Equivalent performance** to ductile structure Advantage: • VCDs **easily inspected** and **replaced** if fuses have activated
Behaviour	• **Viscoelastic Response** • No damage		• **Viscoelastic-Plastic Response** • Fuses **activate**
Performance Benefits	• More **cost-effective** design • **Increased sellable space** • Material reduction		• Much less damage • **Reduces downtime and repair costs** after EQ

Wind and EQ (integrated) Design Philosophy

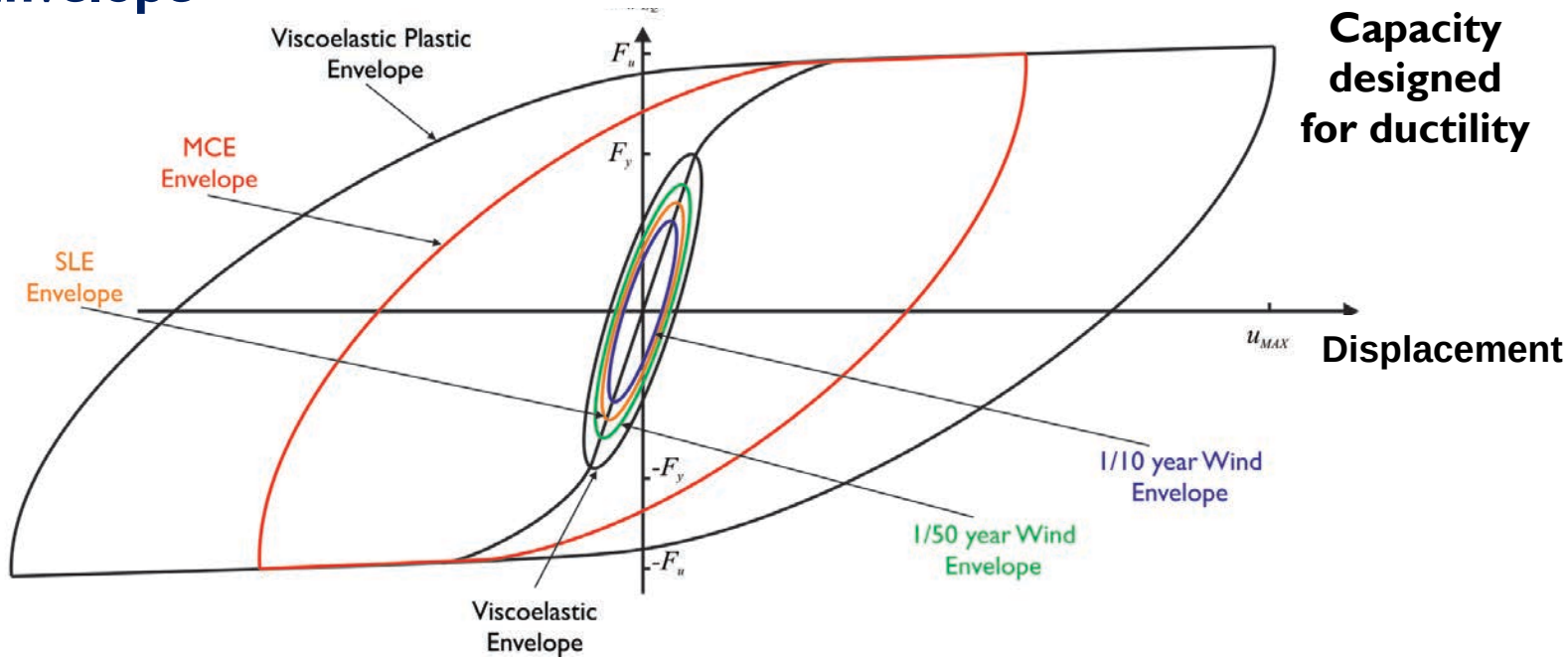
Viscoelastic Response: Added Damping
- **Wind and low level earthquakes**



Viscoelastic-Plastic Response:
- **Maximum Credible Earthquake**



Hysteretic Envelope



VCD vs Current Practice
Maximum Credible Earthquake Response

Coupling Beam Damage During Conception, 2010
LATBSDC (2010)

- **Dampers and walls protected**
- **Damper fully replaceable if required**
- **Enhanced seismic performance compared to coupling beams**

Some Concluding Thoughts

- The earthquake engineering community may want to consider moving away from using ductile structural systems

- In most cases the initial construction cost of advanced systems is very similar to that of conventional systems (a few percent greater than total initial cost of project)

- Owners need to be better educated about potential seismic damage by structural engineers

- Significant research efforts have to be steered in this direction at all levels to achieve this shift in seismic engineering

- Leaders in industry must take part and support this effort if we want to accelerate this shift

Thank You

Acknowledgements

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- Carlos de Oliveira, CEO, Cast Connex Corporation
- Dr. Michael Gray, VP, Cast Connex Corporation

- Professor Robert Tremblay, Ecole Polytechnique de Montreal

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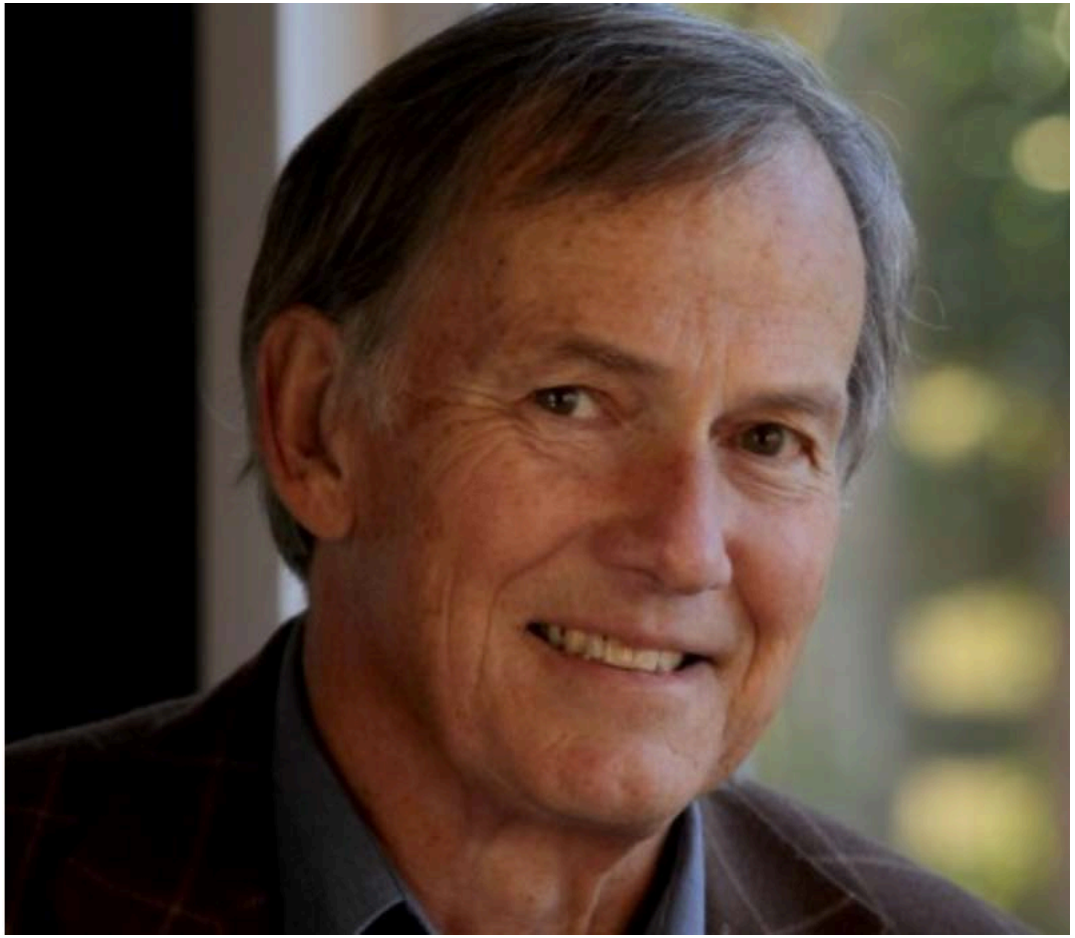
In Memoriam



Professor Nigel Priestley
1943-2014