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New Technologies in Reinforced Concrete

Professor Des Bull

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University of Canterbury

Conventional Buildings- pre -1980

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- Concrete
  - Frames – beams and columns
  - Walls
  - Combination of walls and frames
- Lack on modern seismic engineering
  - Little “toughness” or “resilience”

Harcourts, Madras St - pre -1980s

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Harcourts, Madras St 22 Feb 2011

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Aftershock June 13 2011

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Aftershock June 13 2011

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Aftershock June 13 2011

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Conventional Buildings- post 1980

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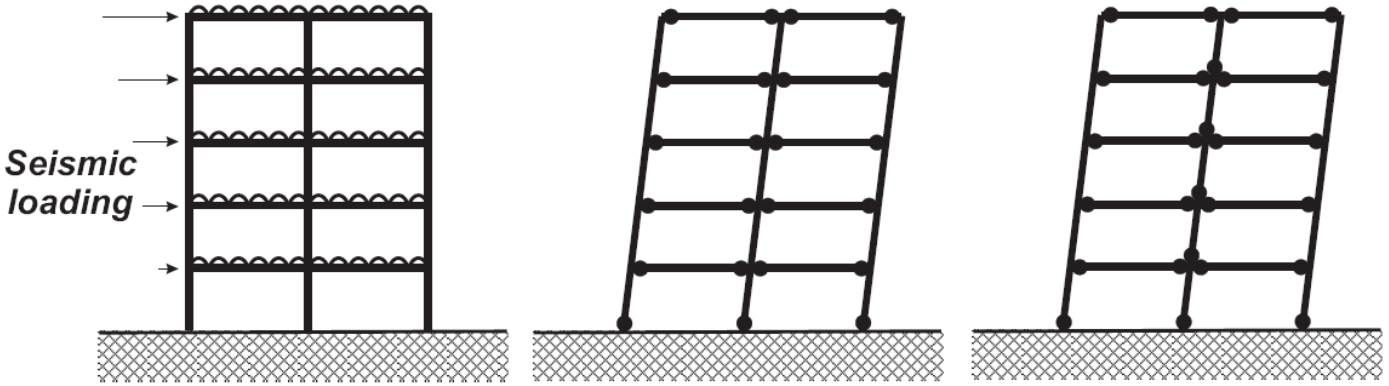
- Concrete
  - Frames – beams and columns
  - Walls
  - Combination of walls and frames

Desirable post-elastic mechanisms in moment resisting frames



(a) Frame with gravity and Seismic loading

(b) Full strong-column weak-beam mechanism

(c) Beam-sway mechanism

Critical Structural Issues

- Conventional Beams:
  - Yield or go plastic
  - Elongate under cyclic loading from earthquake
    - Concrete worst
    - Then steel
    - Then timber (in connection hardware)
  - Loss of floor support
  - Loss of load path across

Plastic Hinge in a RC Beam

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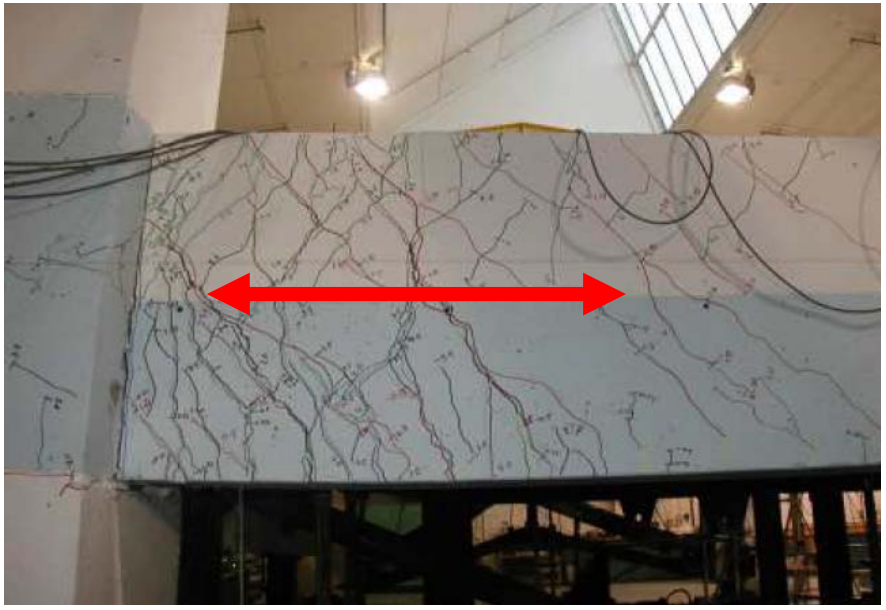
- Conventional Beams:
  - Yield or go plastic
  - Elongate under cyclic loading from



UoC Test

J Matthews

Elongation of the beams – push the columns

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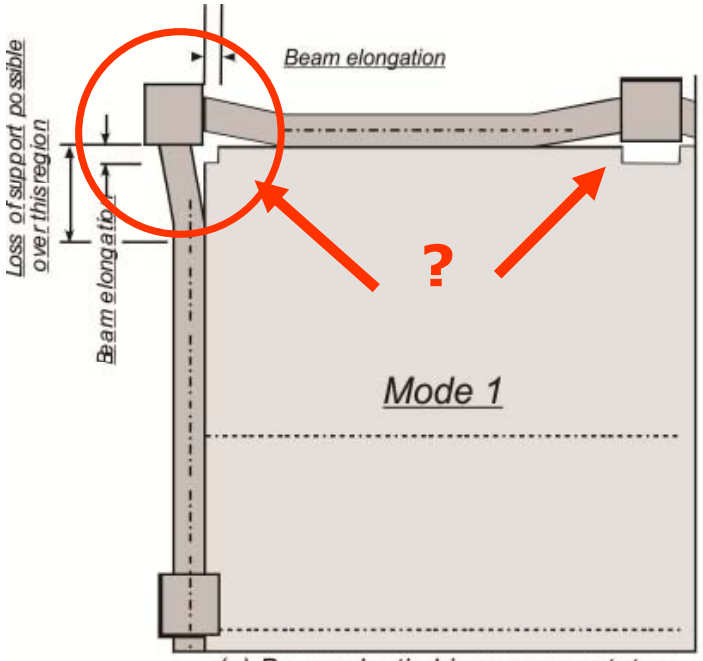
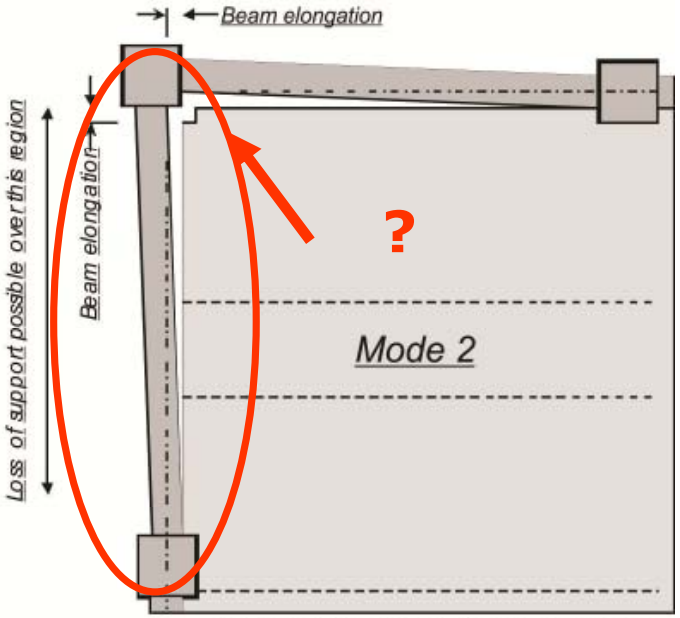
- Loss of connection: floor - supports



(a) Beam plastic hinge zone rotates to allow for beam elongation



(b) Entire beam rotates to allow for beam elongation

Matthews et al 2008

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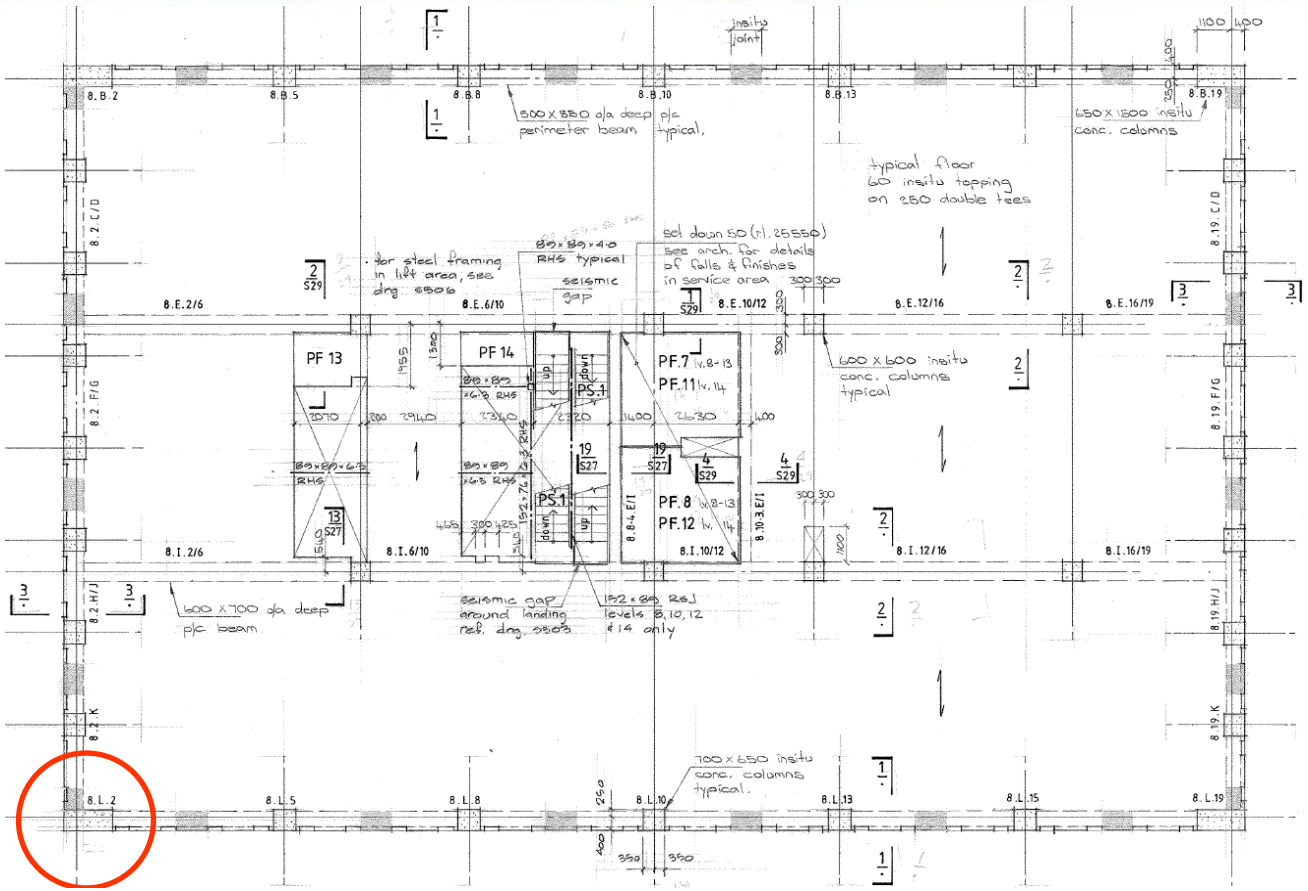
Clarendon, Chch 2011

Clarendon, 1987



N-W corner column

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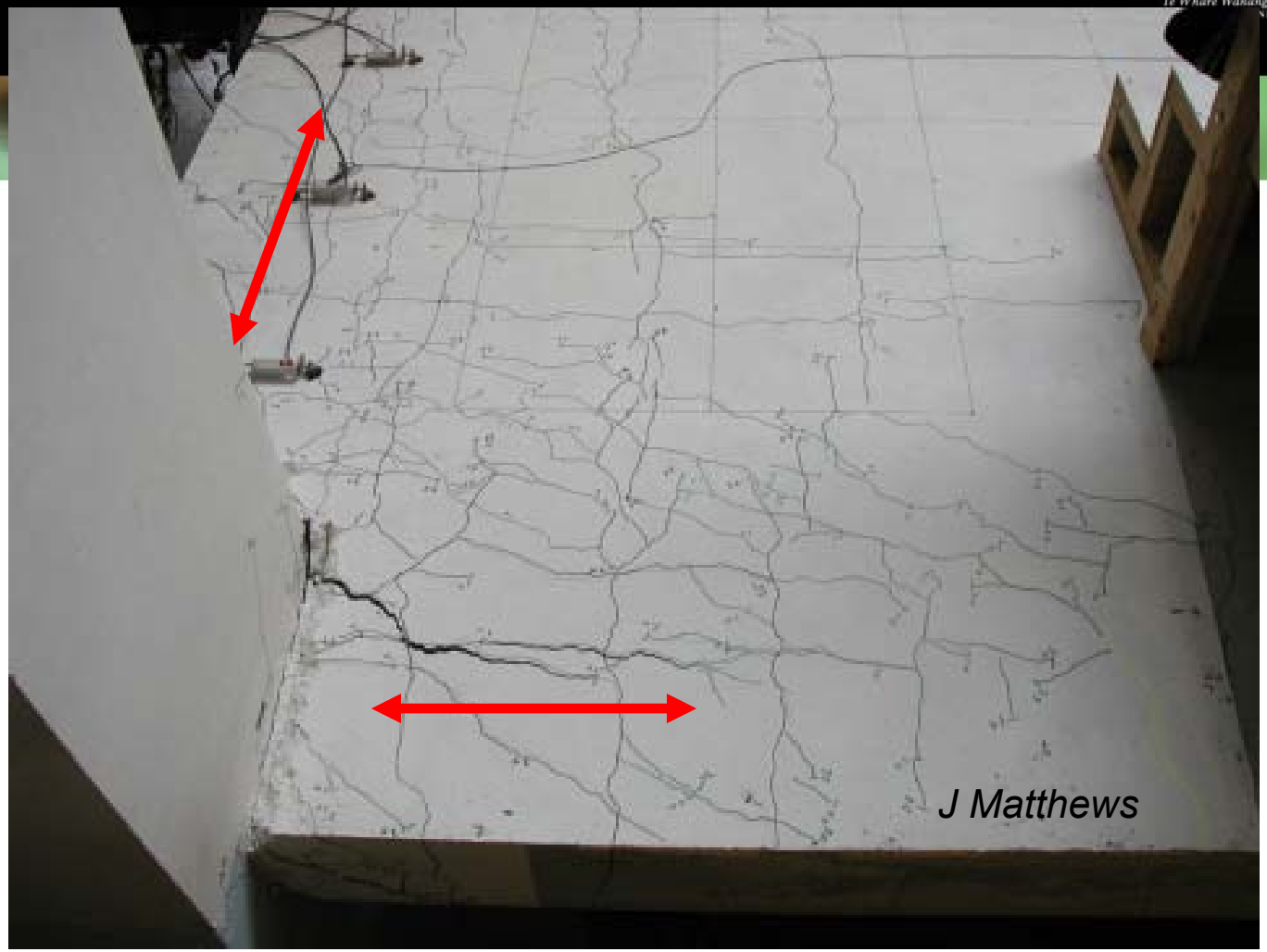
Corner pushed out

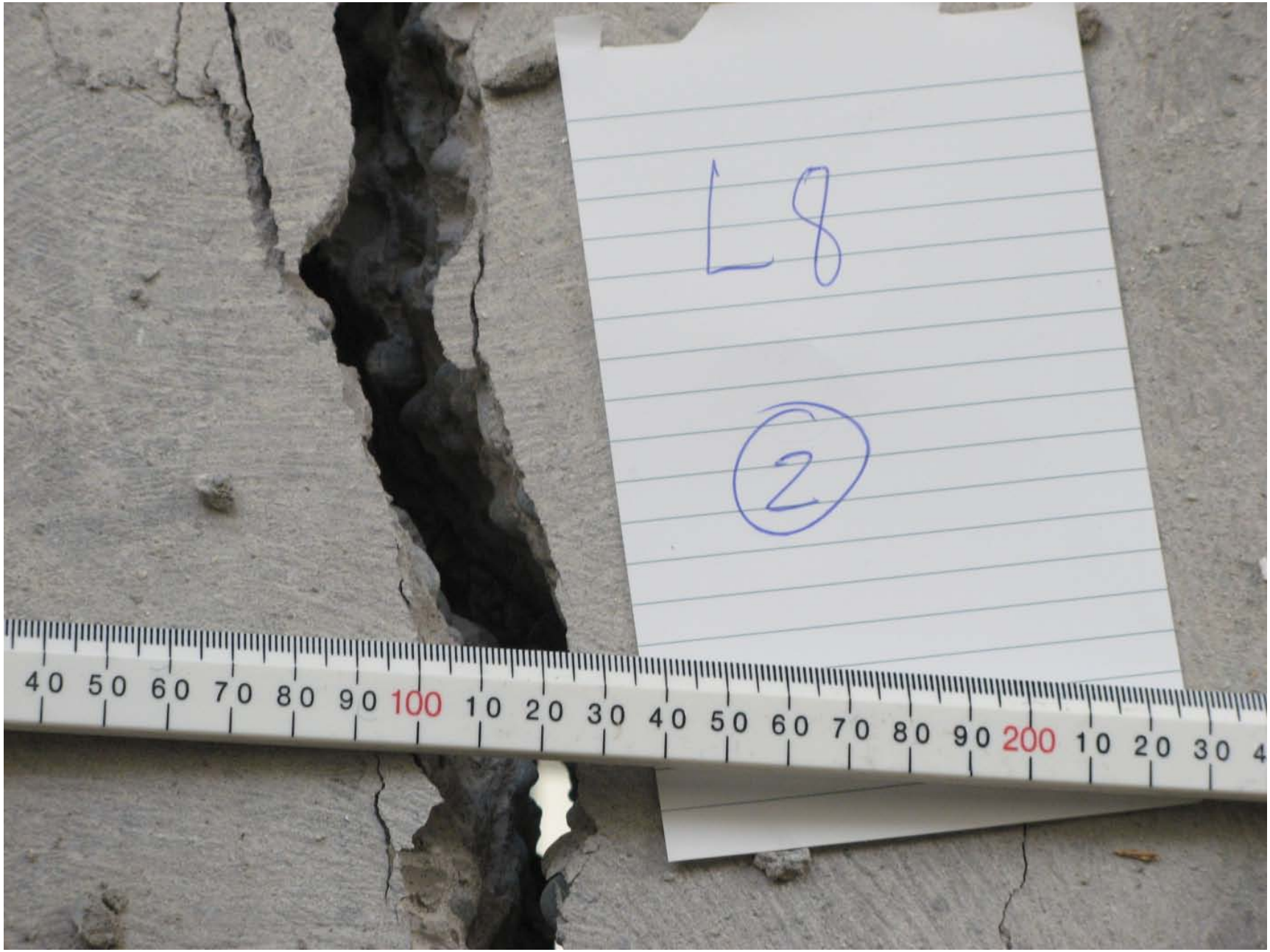
UoC testing Corner column - top view



Clarendon

Clarendon

- Middle bay


L8
2
40 50 60 70 80 90 100 10 20 30 40 50 60 70 80 90 200 10 20 30

UoC Testing – Partial Collapse of the first h/c unit

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J Matthews

UoC testing - Total Collapse of the Floor

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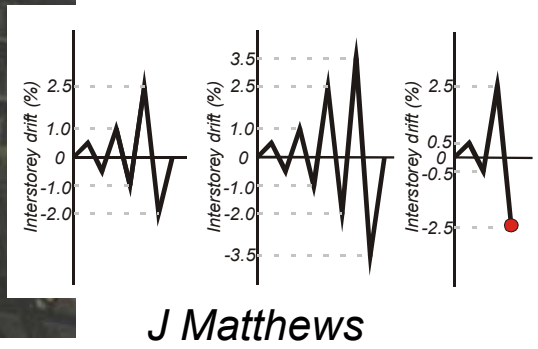

J Matthews

Post-tensioned Frames & Walls

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- PREcast Seismic Structural Systems (PRESSS)
  - Japan & USA research programme
  - Beams and columns
  - Walls
  - Tested San Diego 1995

New Generation of Damage-Resisting systems

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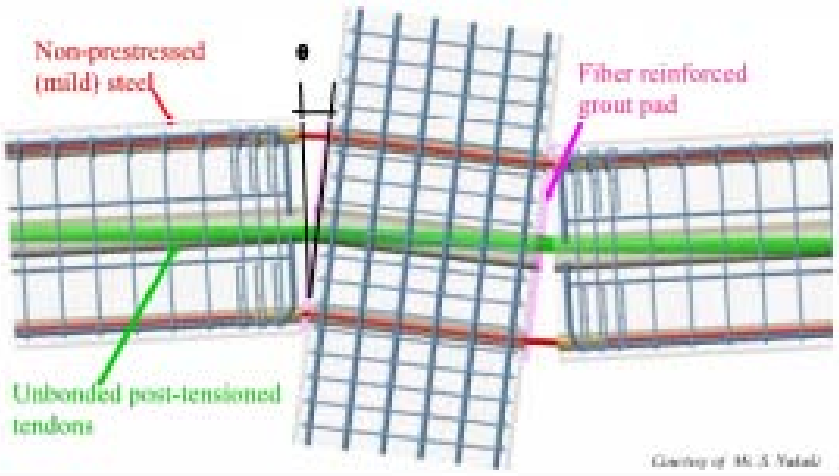
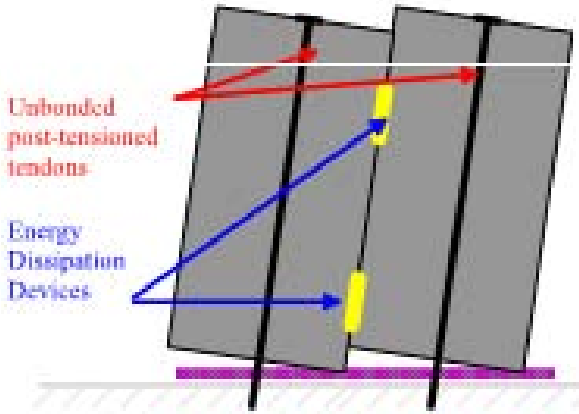
- **Jointed Ductile** DRY connections assembled by post-tensioning techniques
- inelastic demand accomodated within the connection
- **Hybrid systems** : combination of unbonded post-tensioning AND dissipaters
- **"Controlled Rocking"** :
  - Reduced *level of damage*
  - Negligible *residual (permanent) deformations* (recentering)

FRAMES

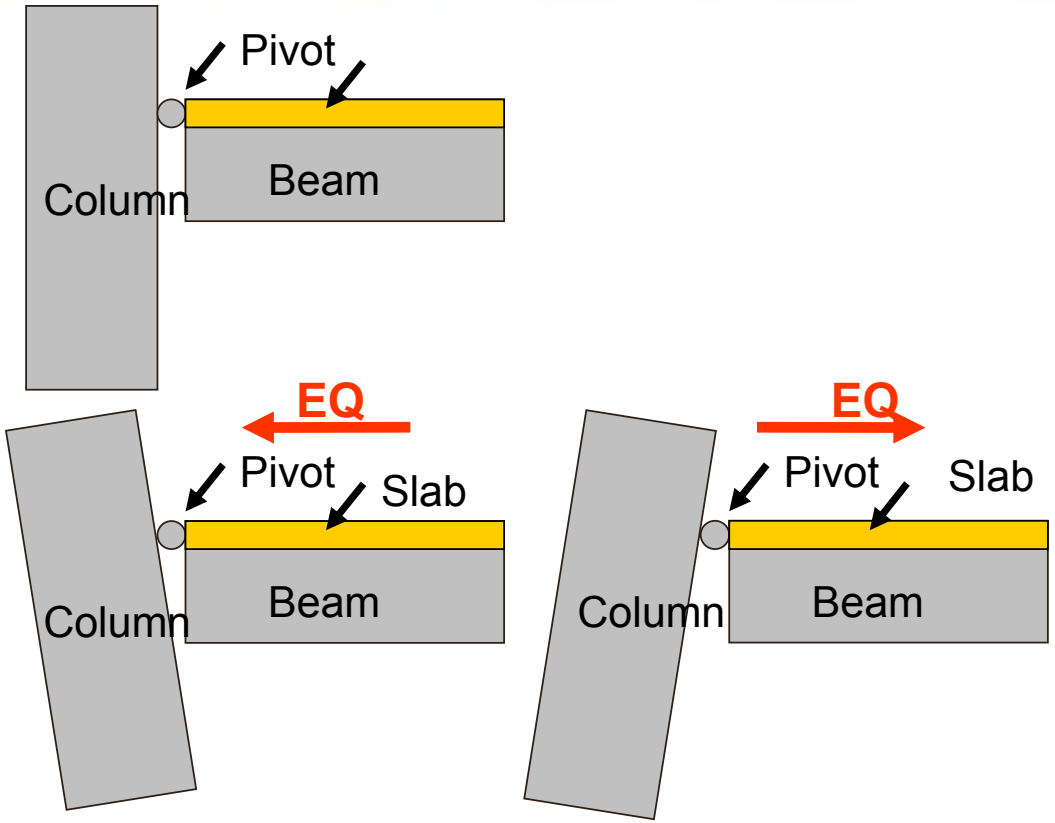


WALLS

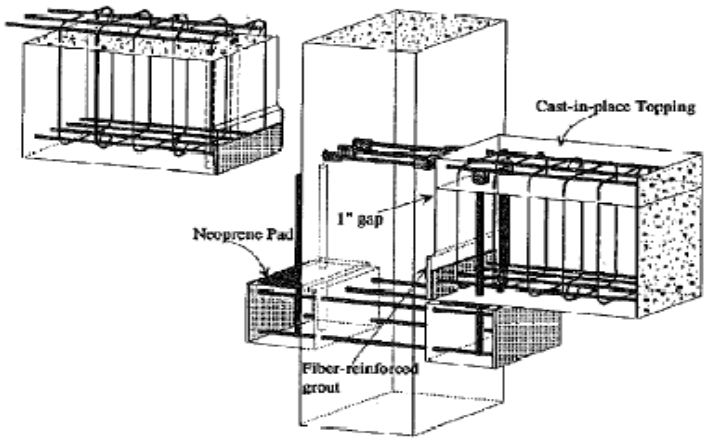


S Pampanin 2012

Pivot or hinge detail

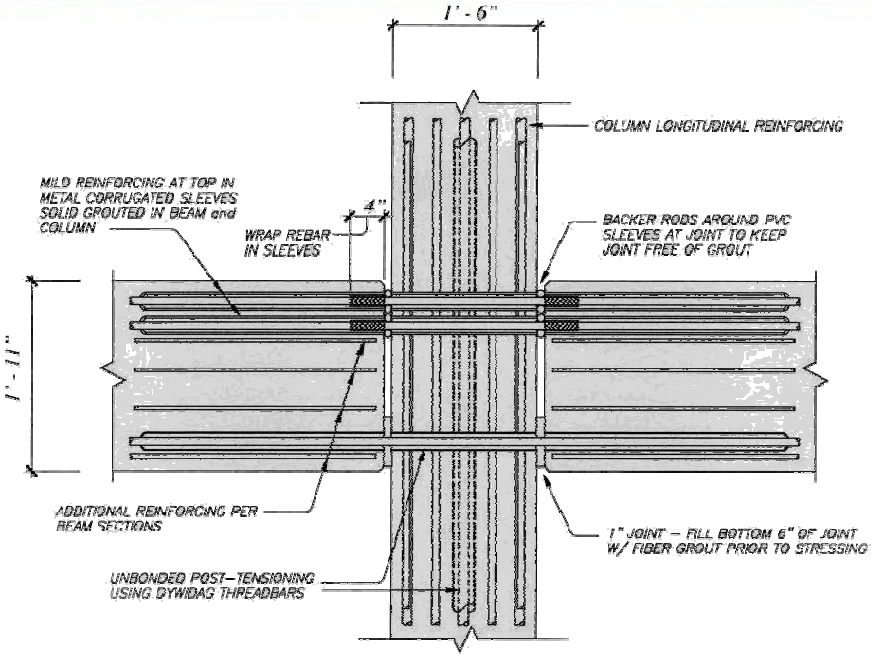


PREcast Seismic Structural Systems (PRESSS)



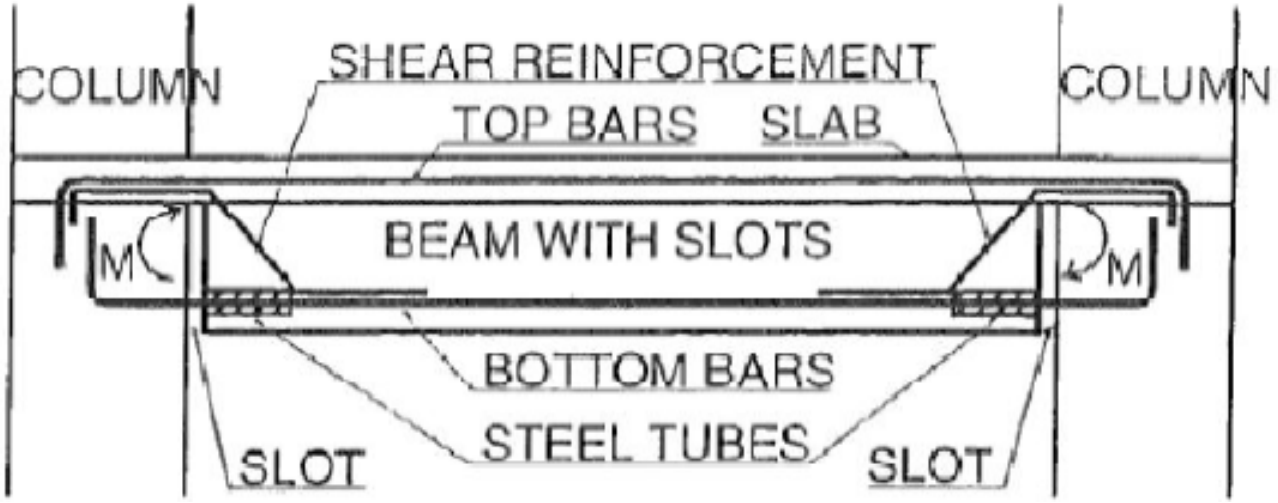
UT-GAP connection

Palmieri, Saqan et al. 1996



TCY gap connection in PRESSS five-storey frame Nakaki et al., 1999

Early Japanese reinforced concrete slotted beam (1999)



Ohkubo, Matsuoka et al. 1999

Conventional concrete frame

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- Fracture of main bars

Slotted Beams & "Non-tearing" floors

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- New configurations of typical building materials
  - At slab level – beam pivots – like a small hinge
  - Very little damage to the floors – doesn't "tear".
  - Structural Steel and Concrete options
  - Timber will work too.

The Non-Tearing Floor System

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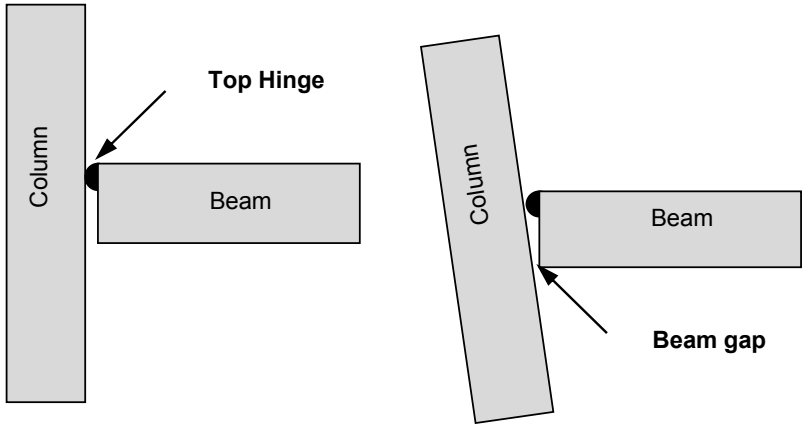
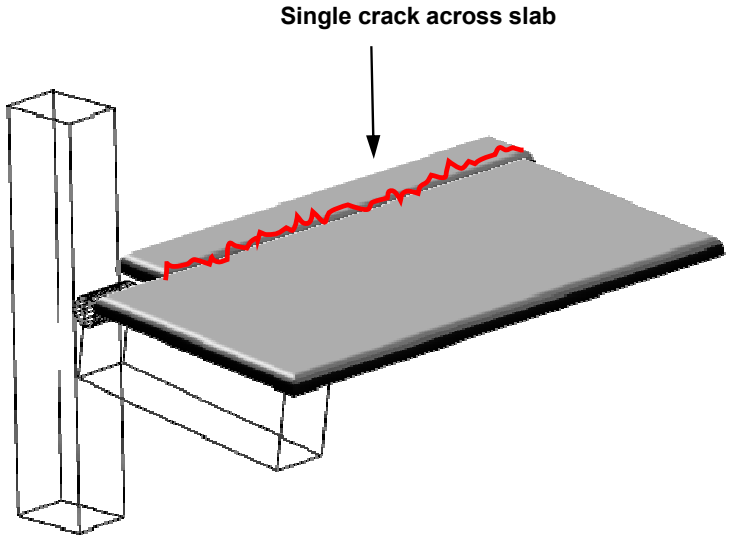
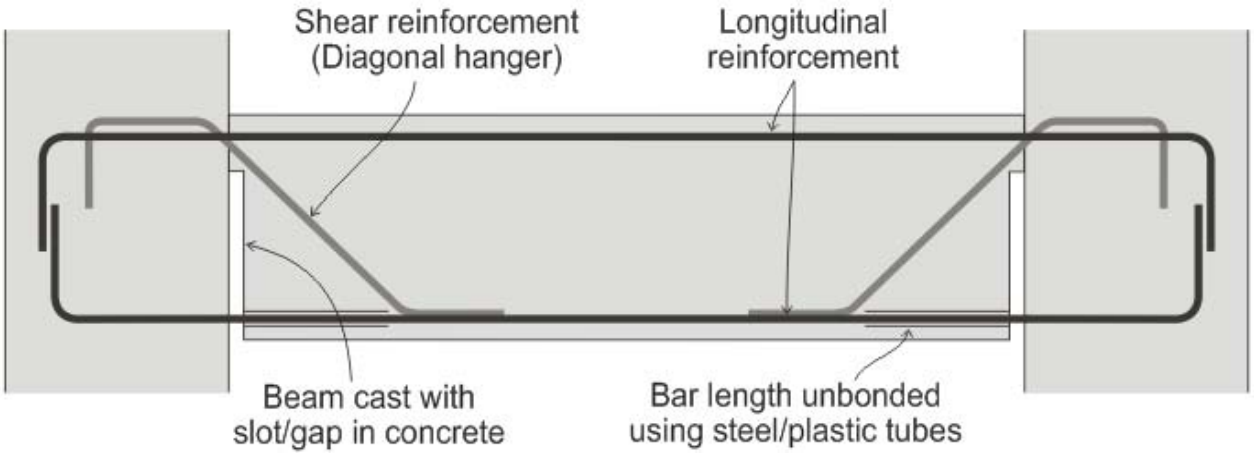




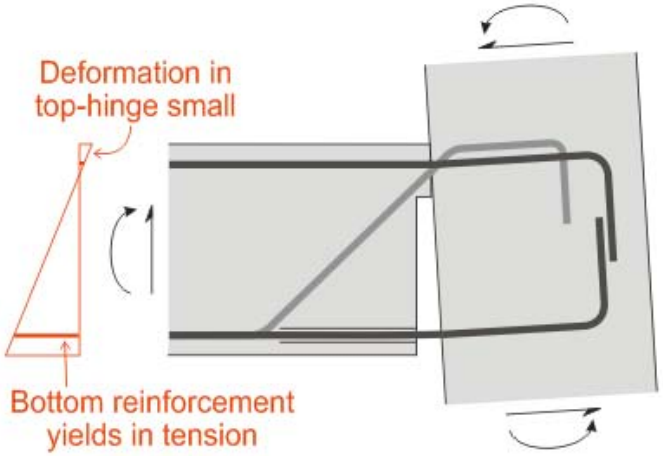
Slotted reinforced concrete beam



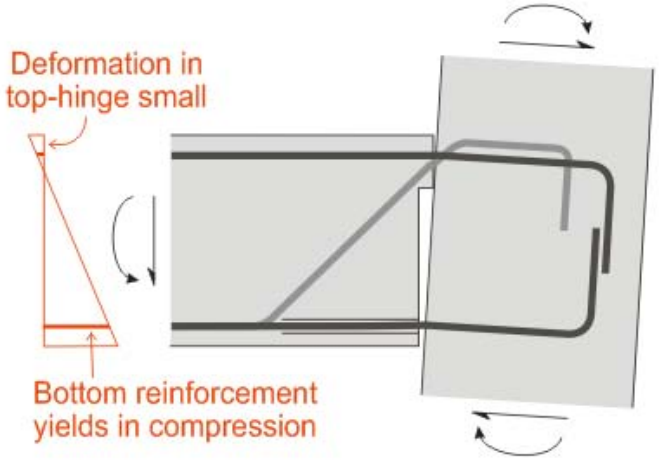
- FRST “Future Buildings” Programme

E Au 2010

Accommodation of rotation via opening and closing of slot

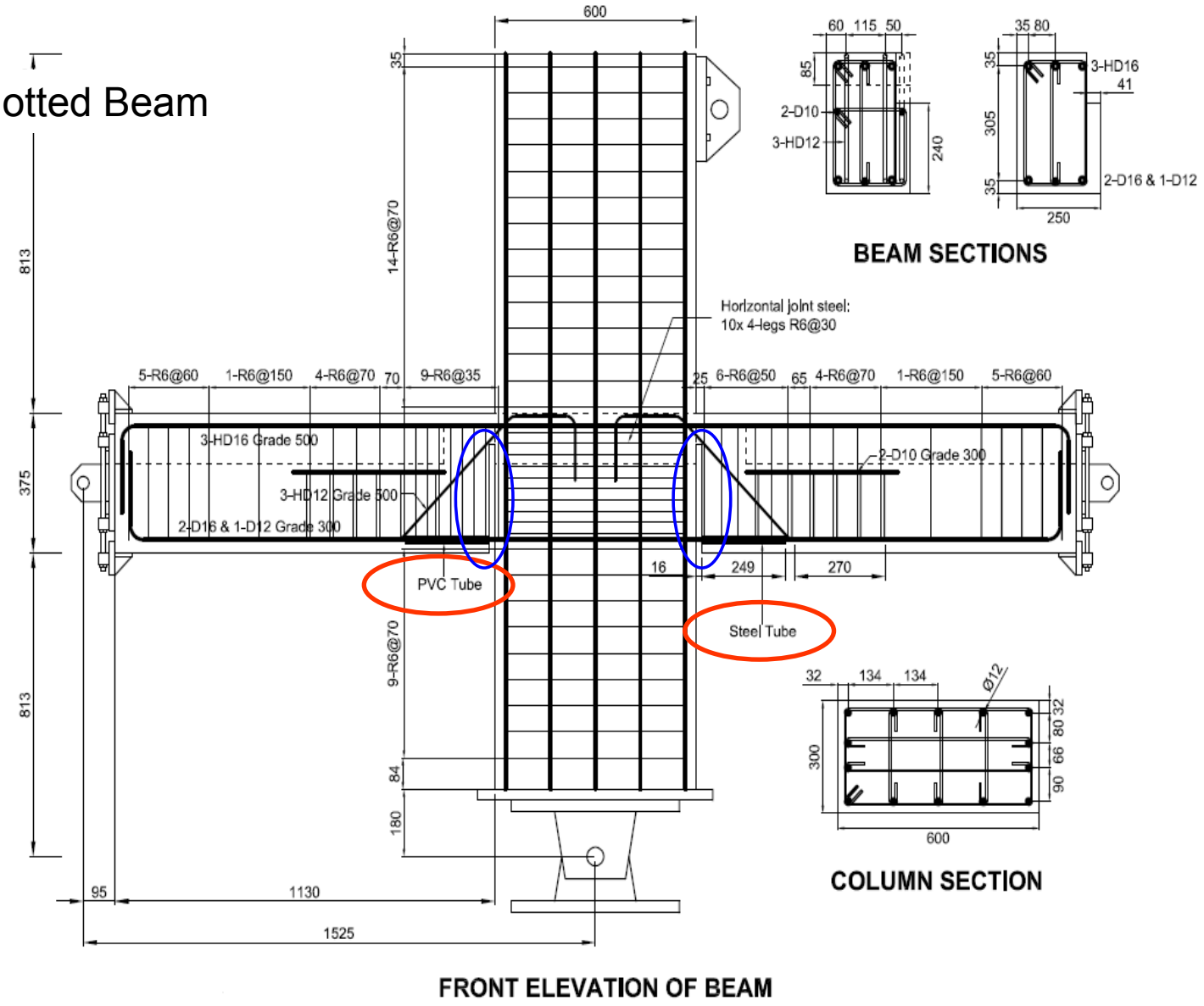


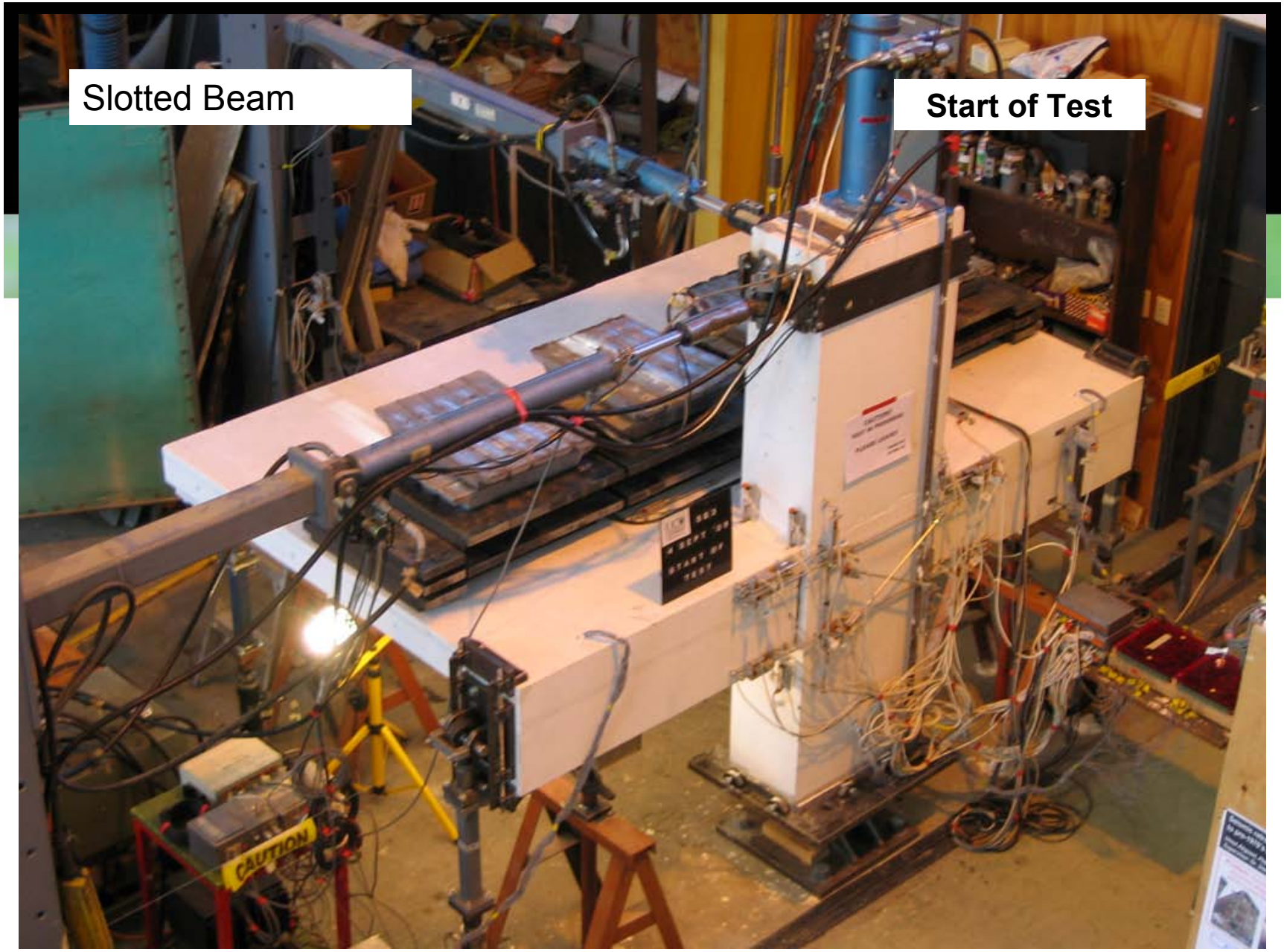
(a) Positive (gap opening) moment

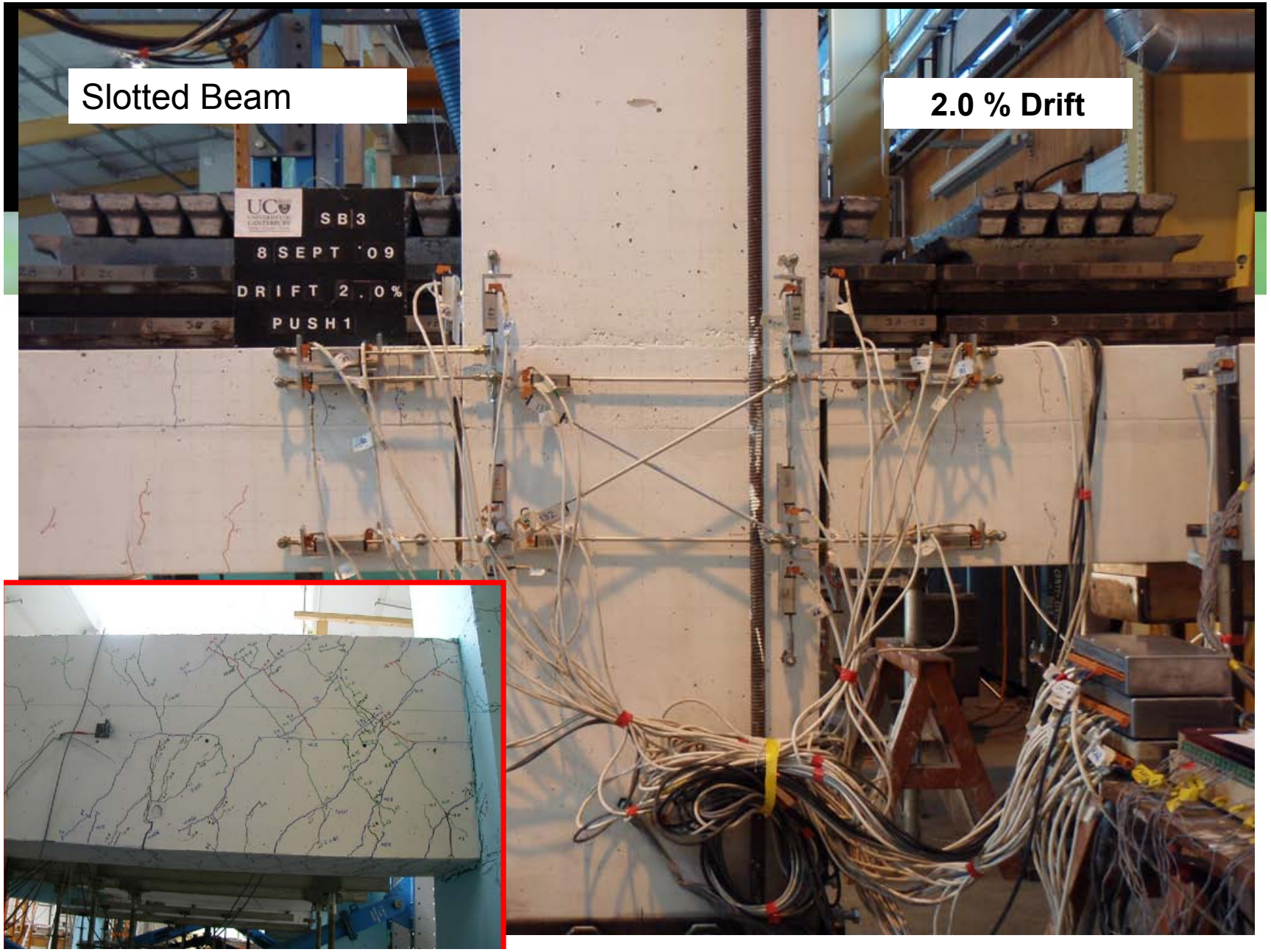


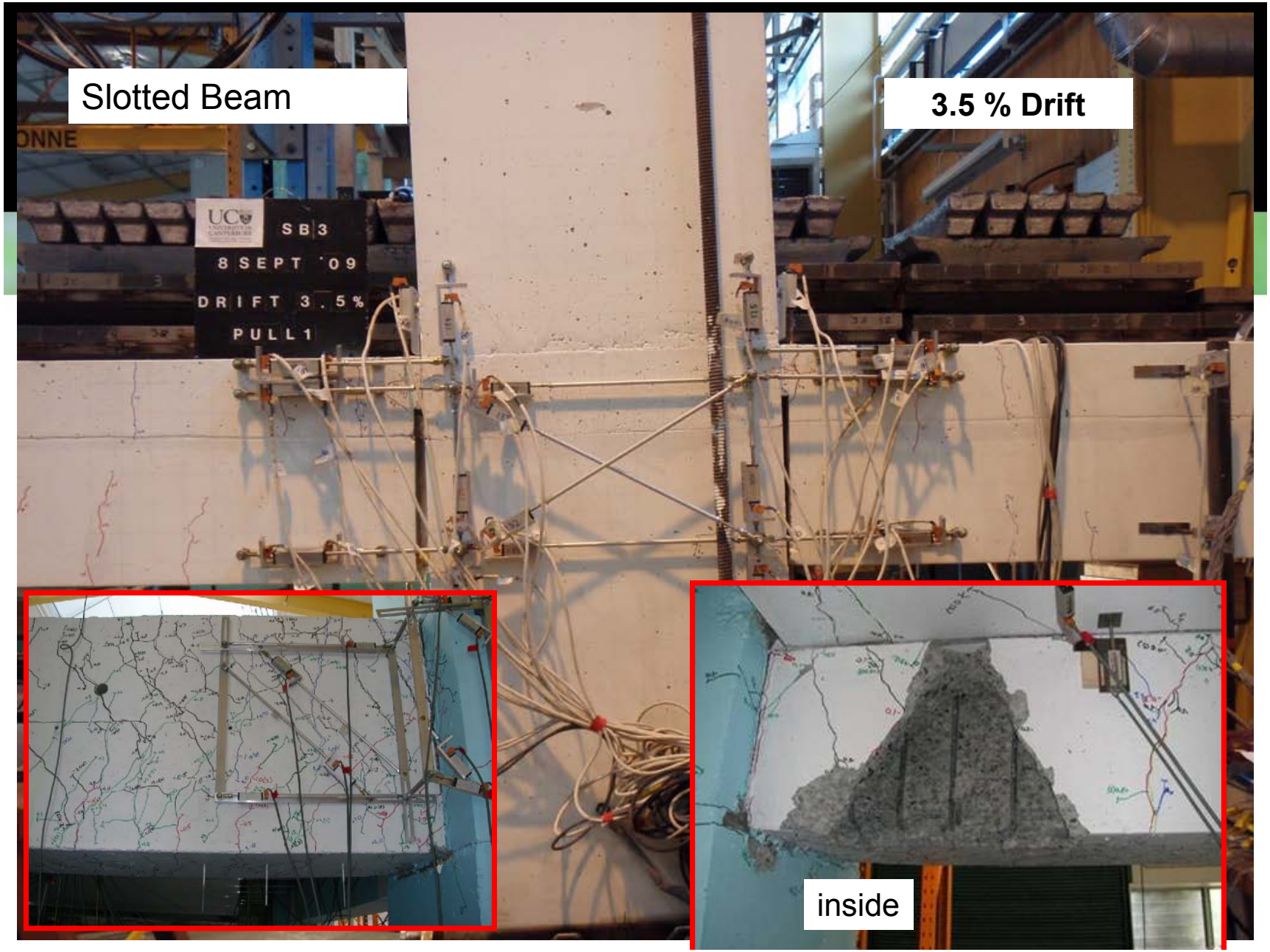
(b) Negative (gap closing) moment

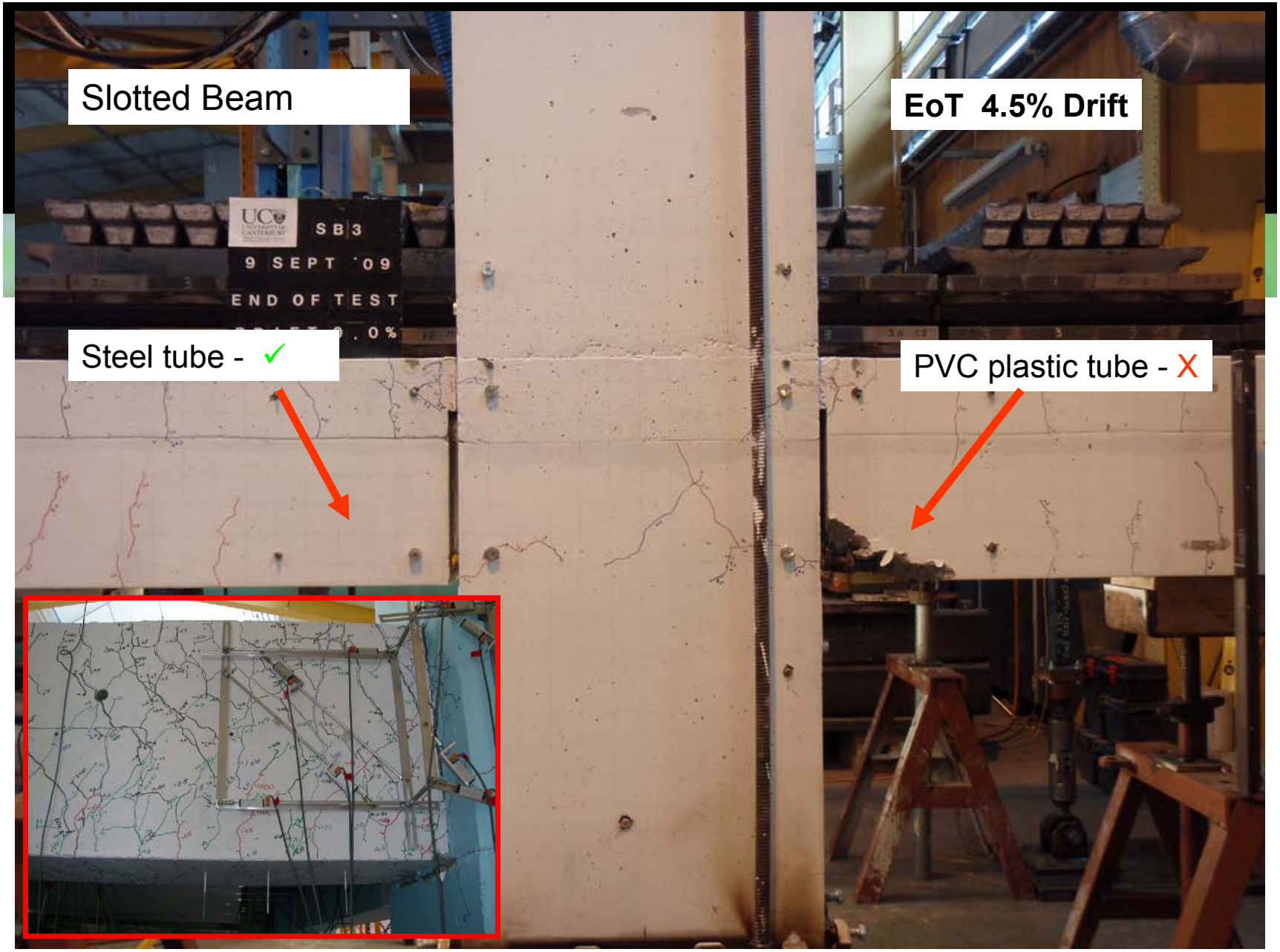
Slotted Beam

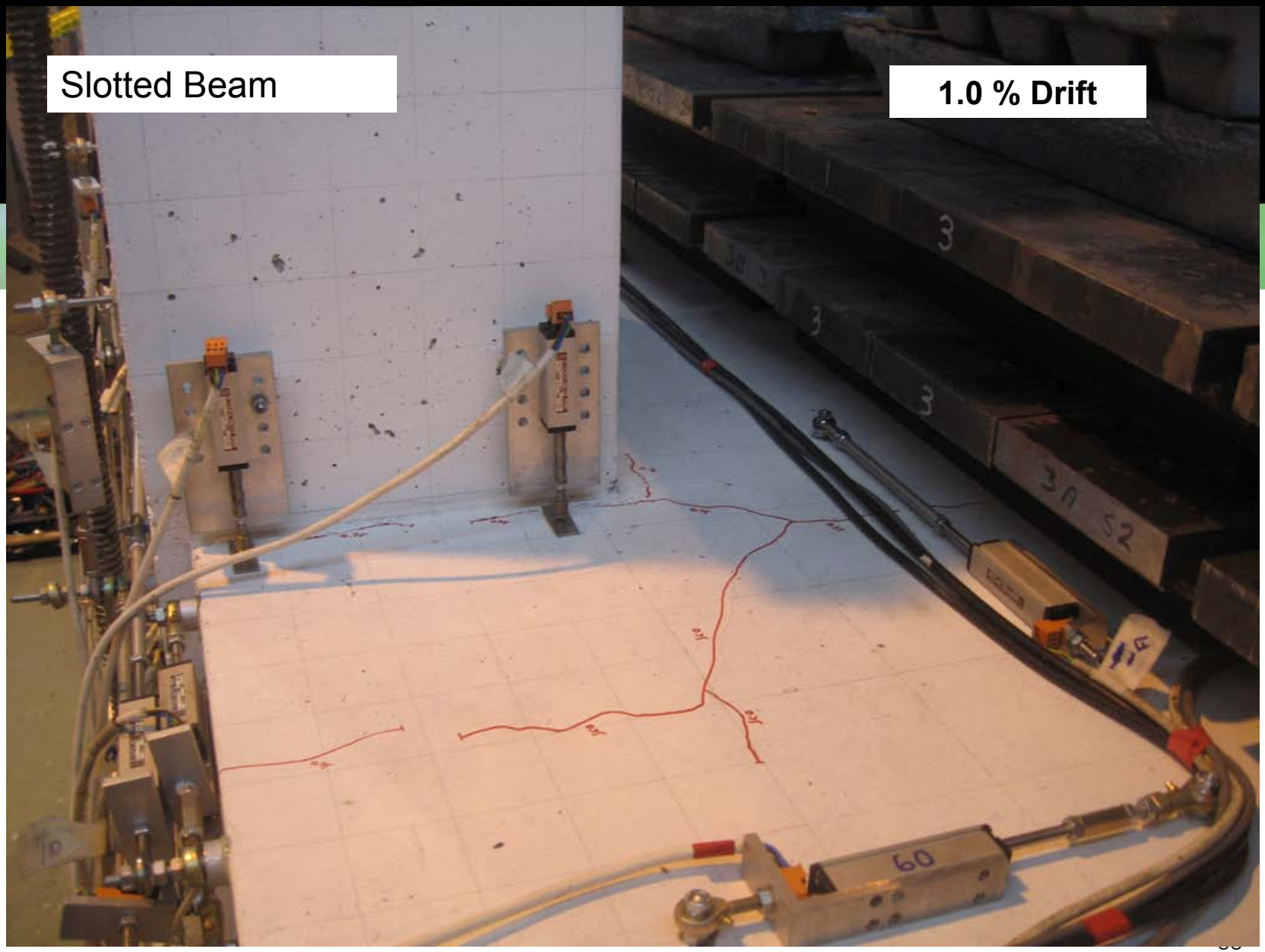


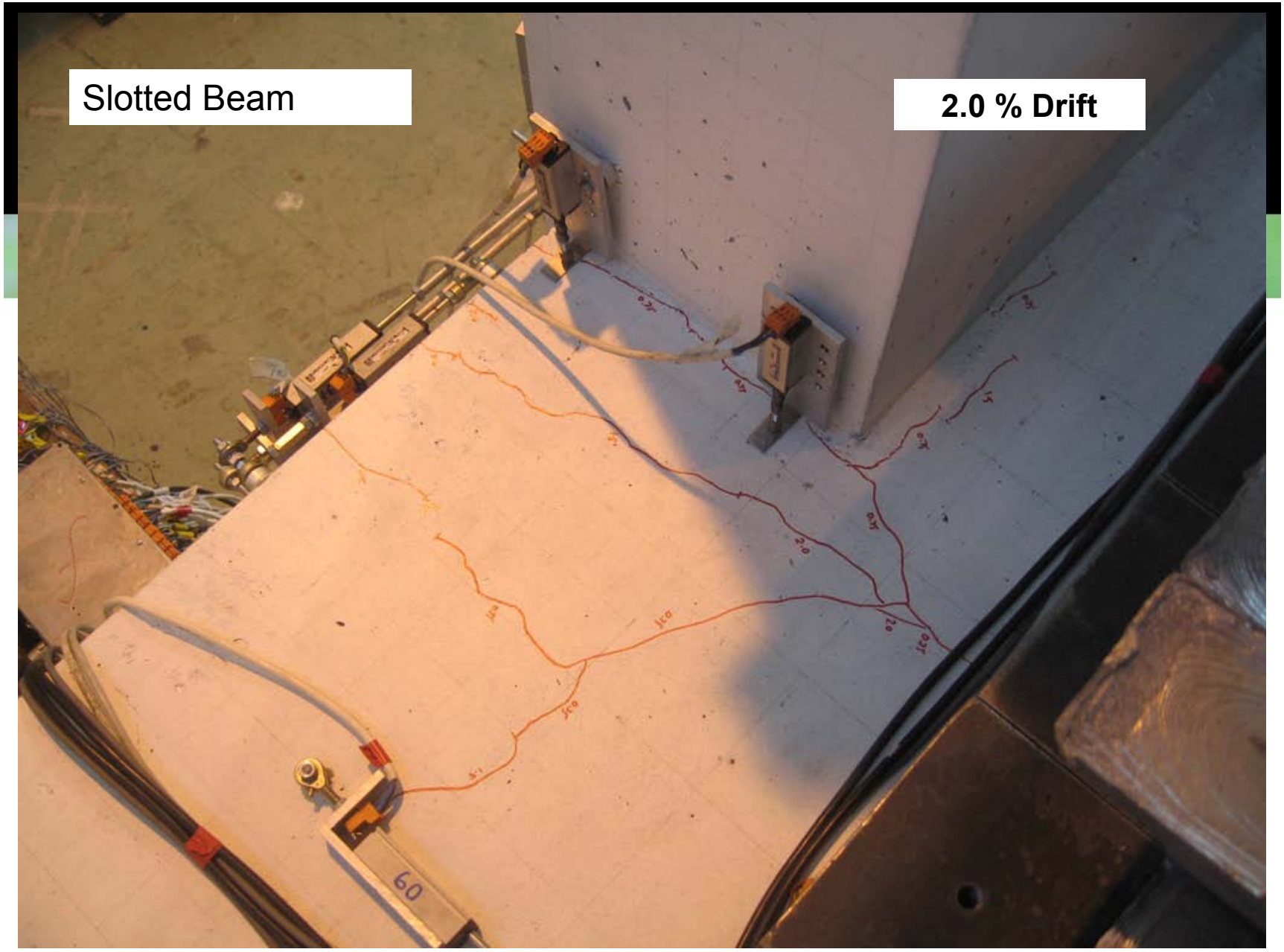

Slotted Beam
Start of Test
CAUTION

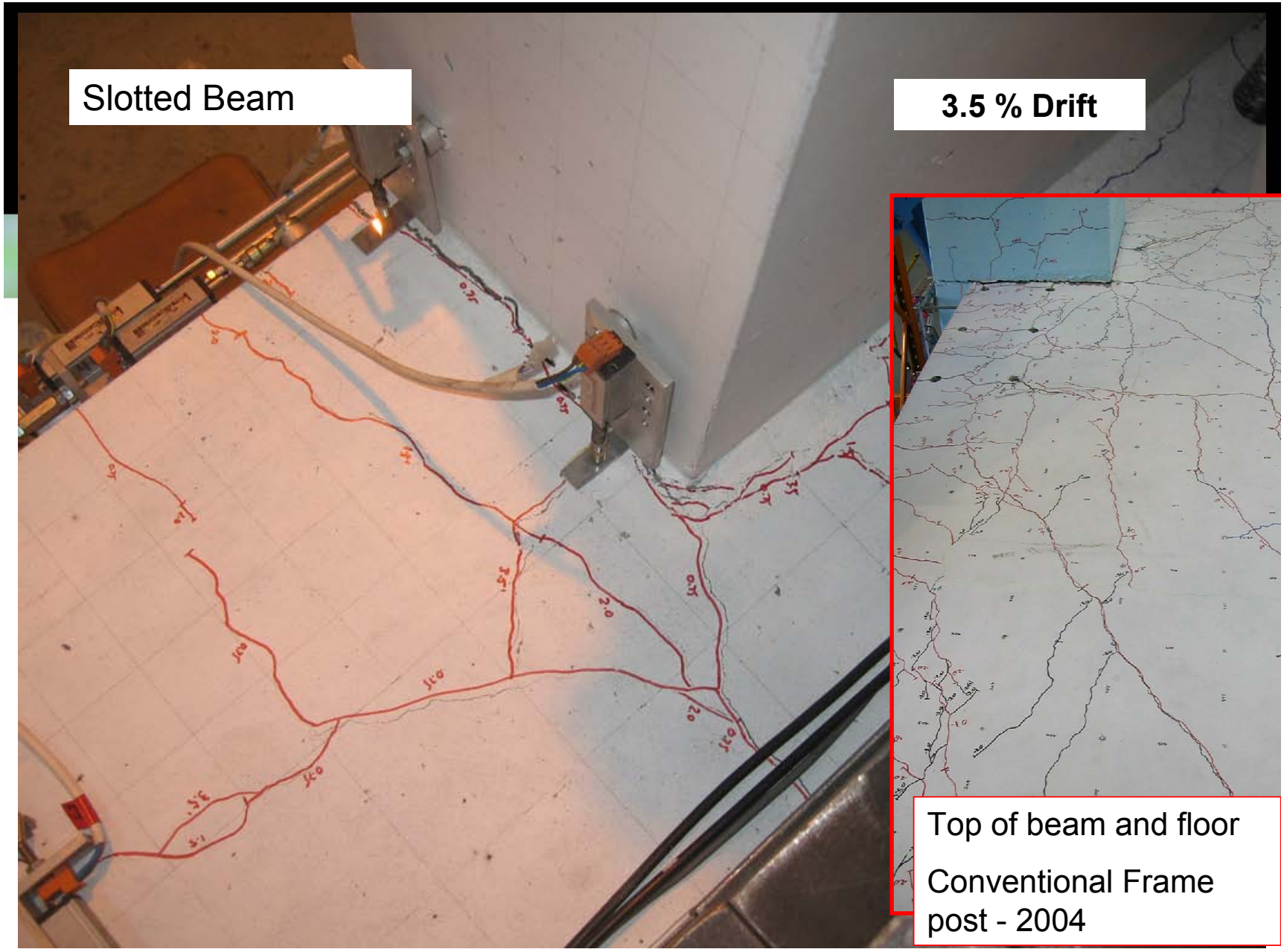

Slotted Beam
2.0 % Drift
UC
SB3
8 SEPT '09
DRIFT 2.0%
PUSH1

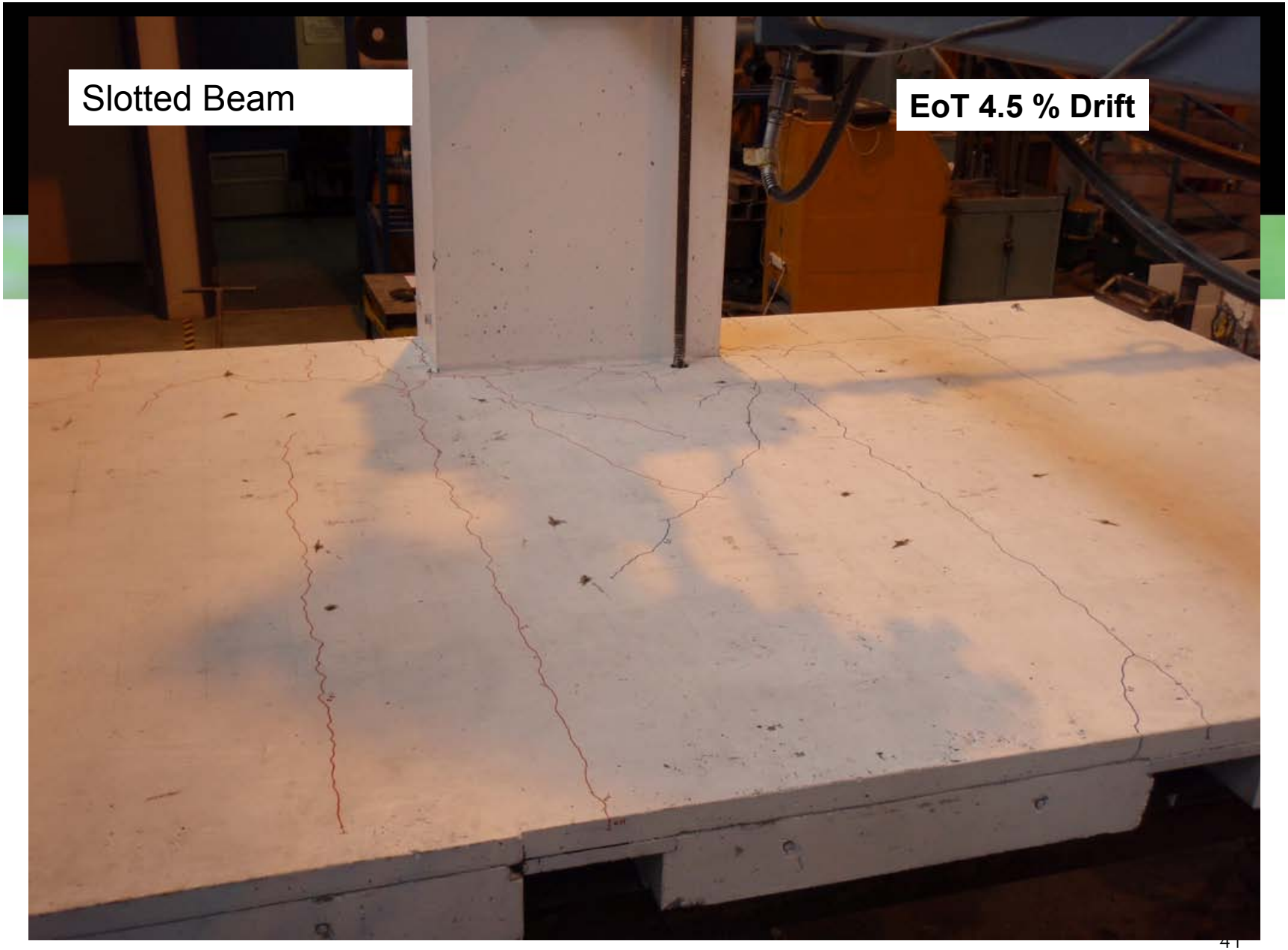

Slotted Beam
3.5 % Drift
SB3
8 SEPT '09
DRIFT 3.5%
PULL1
inside


Slotted Beam
EoT 4.5% Drift
SB3
9 SEPT '09
END OF TEST
Steel tube - ✓
PVC plastic tube - X


Slotted Beam
1.0 % Drift
60


Slotted Beam
2.0 % Drift


Slotted Beam
3.5 % Drift
Top of beam and floor
Conventional Frame post - 2004


Slotted Beam
EoT 4.5 % Drift

Conventional RC Frame

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2 Storey, "Non-tearing" Precast Concrete Floor / slotted beams

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C Muir et al

2 Storey, "Non-tearing" Precast Concrete Floor / slotted beams

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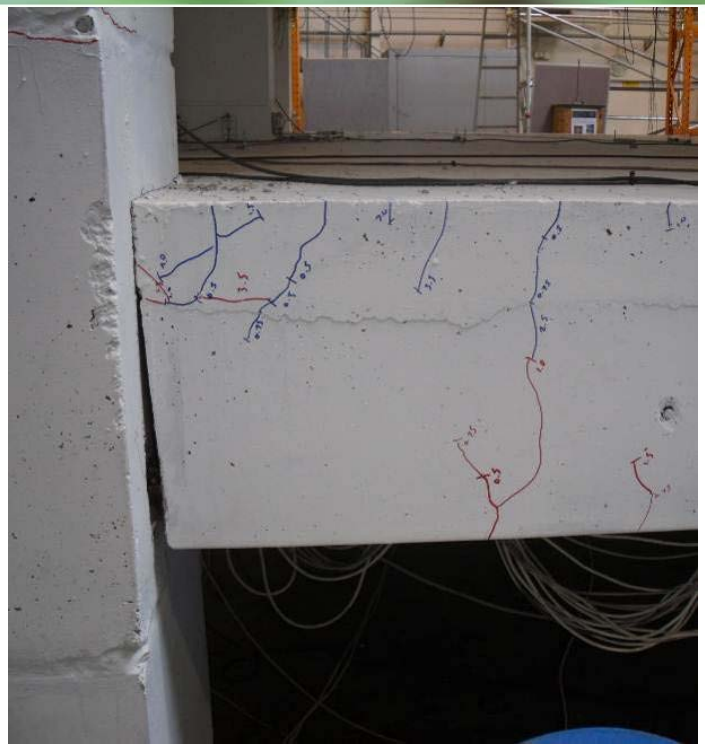
2 Storey, "Non-tearing" Precast Concrete Floor / slotted beams



Slotted Beam at ULS

Monolithic Beam at ULS
(MacPherson, 2005)

2 Storey, "Non-tearing" Precast Concrete Floor / slotted beams

Slotted system floor at ULS

Monolithic system floor at ULS (Lindsay, 2004)

Results

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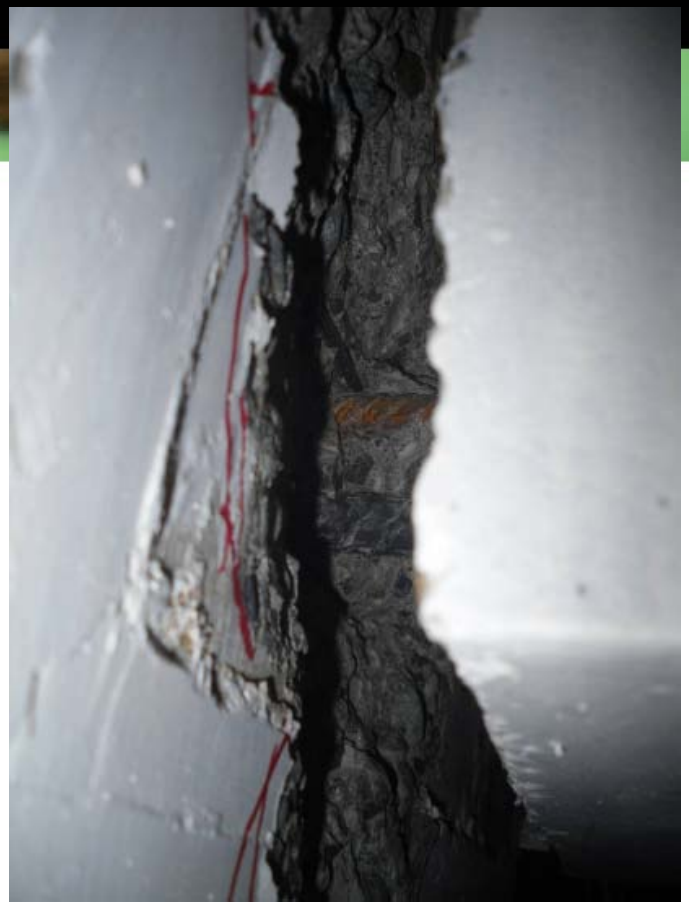
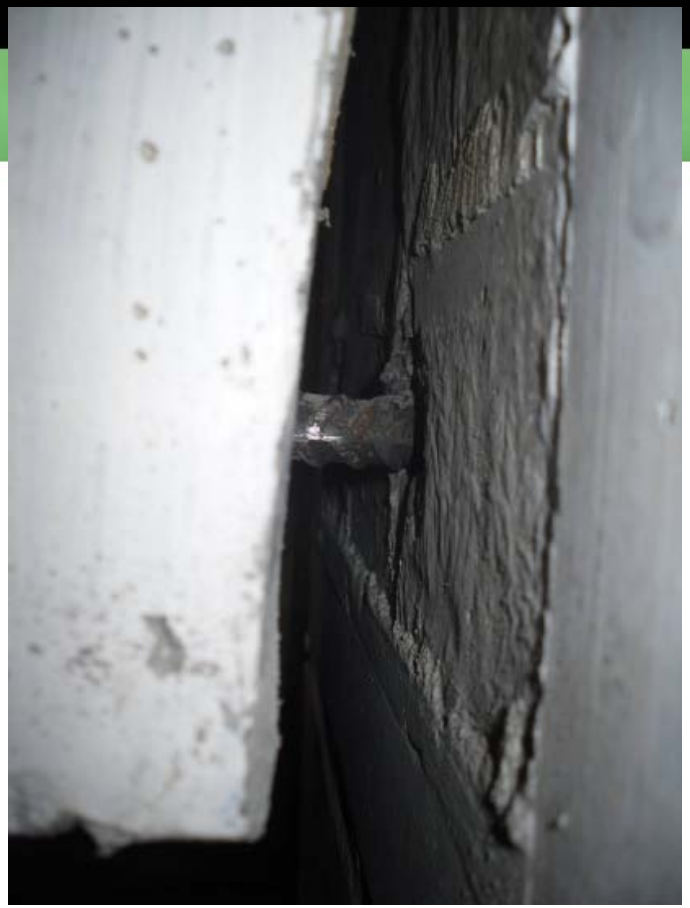


Exterior joint strain penetration



Interior joint strain penetration

Replaceable external mild steel energy dissipaters

- Instead of internal mild steel bars
  - Very hard to repair

Pampanin (2005) and Pampanin, Amaris, Akguzel, and Palermo (2006)

Non-tearing floor connection details
Variations on the Concept

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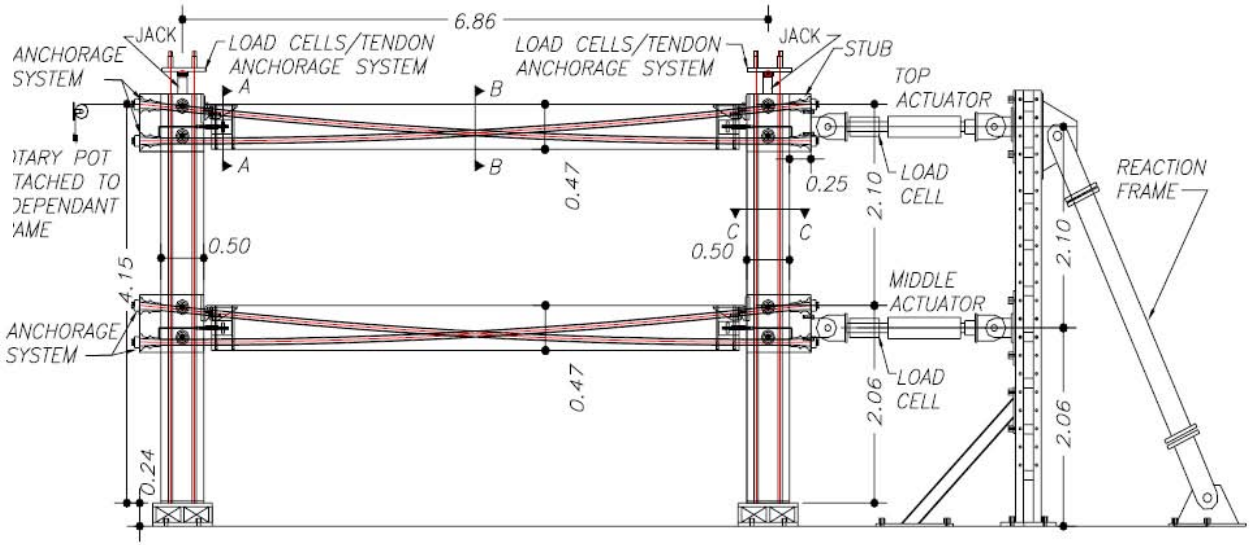
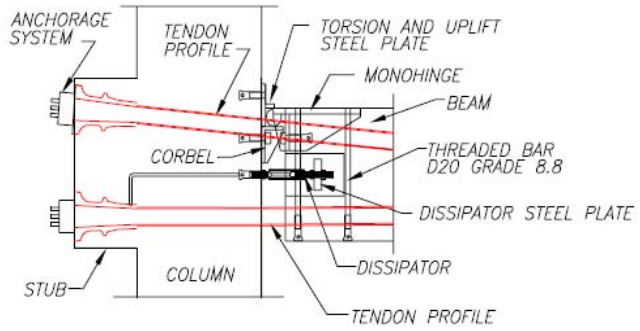
Two-storey, one-bay frame tested

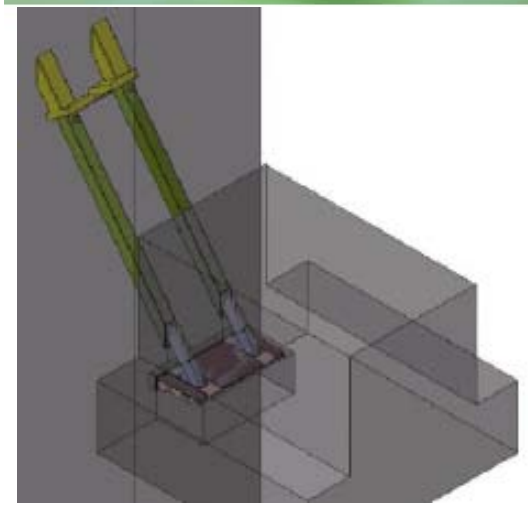




- "self-centring"

Amaris et al., 2008

Alternative solutions of steel shear corbel/bracket



“Hercules” systems,
proprietary of B.S. Italia srl

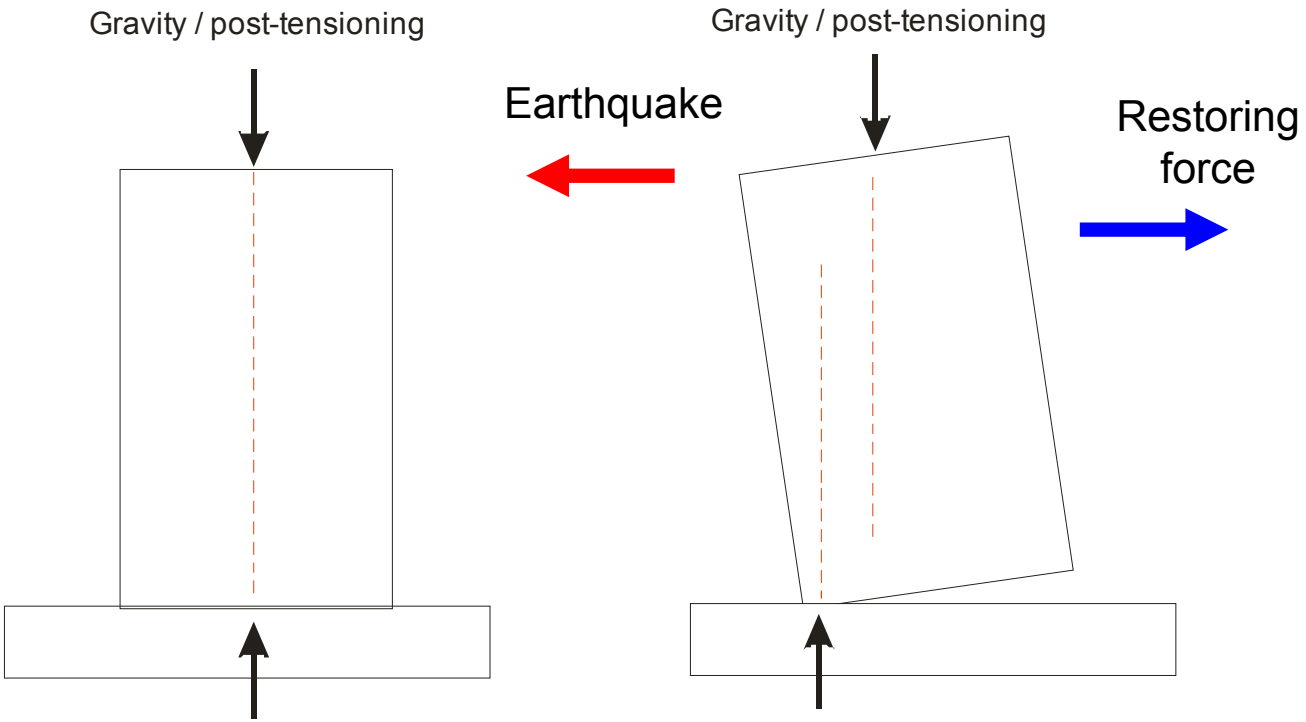
Walls

- Conventional
  - Damaged and costly to repair, if possible.

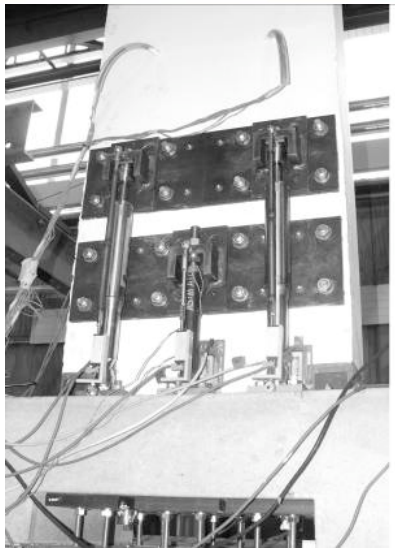
Grand Chancellor

123 Victoria St

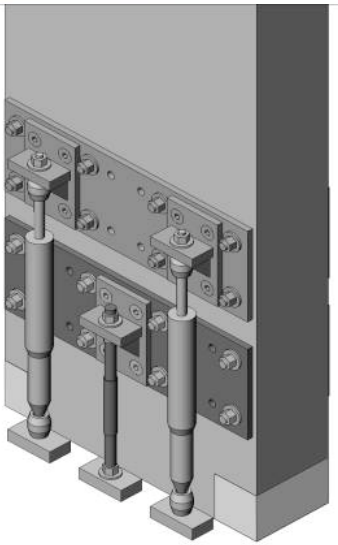
New Technologies – rocking wall



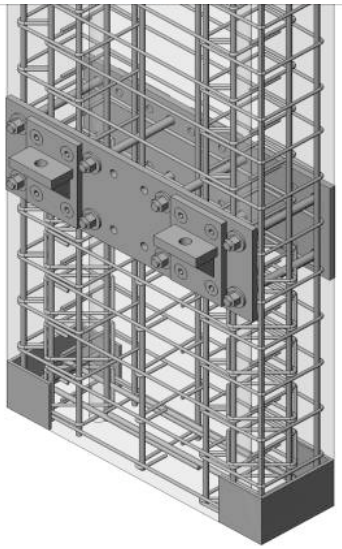
Rocking walls: post-tensioned, bar dampers and viscous dampers



(a) As-built post-tensioned wall



(b) Connection detail



(c) Reinforcement, confinement and steel bracket details

Marriott et al 2008

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- Thank you.