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FASTER CONSTRUCTION AND BETTER SEISMIC PERFORMANCE:

YOU CAN HAVE BOTH

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Acknowledgments

- NSF NEES
- PEER Center
- FHWA Highways for Life
- WSDOT

Performance Goals

- Accelerate Construction

- Minimize Residual Displacements

- Reduce Column Damage

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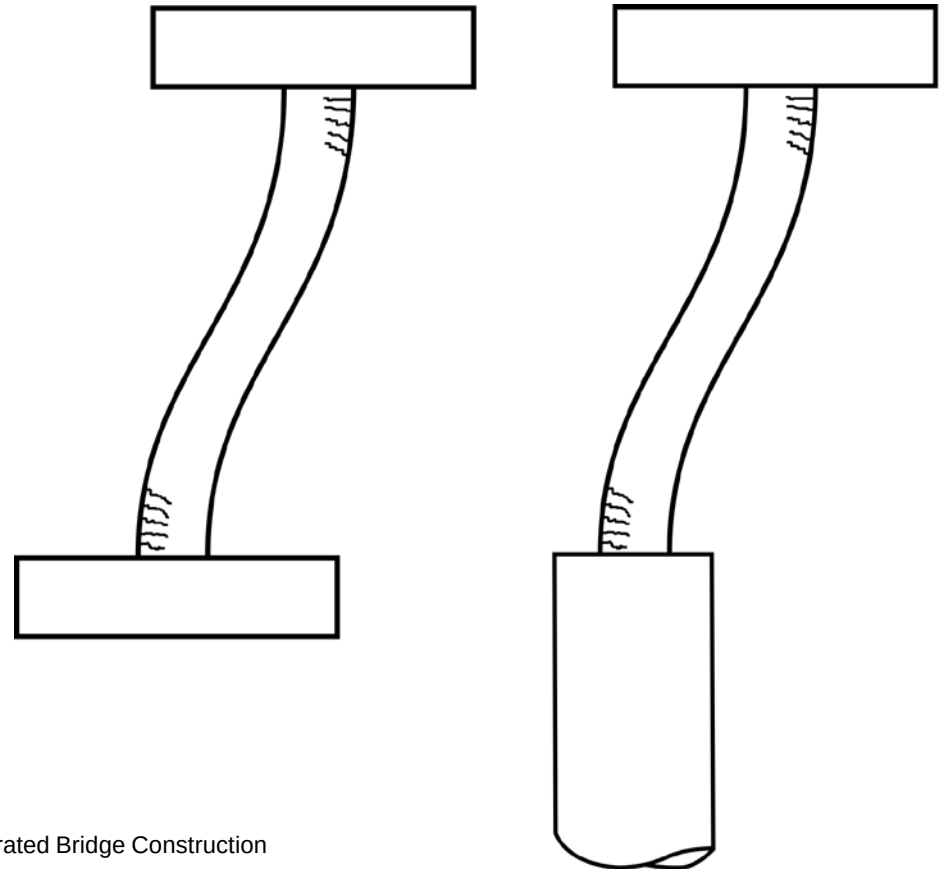
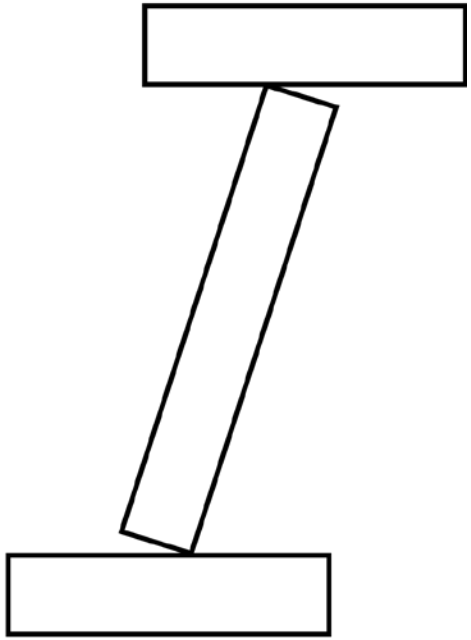
Accelerated Bridge Construction

Systems Developed

Emulative connections



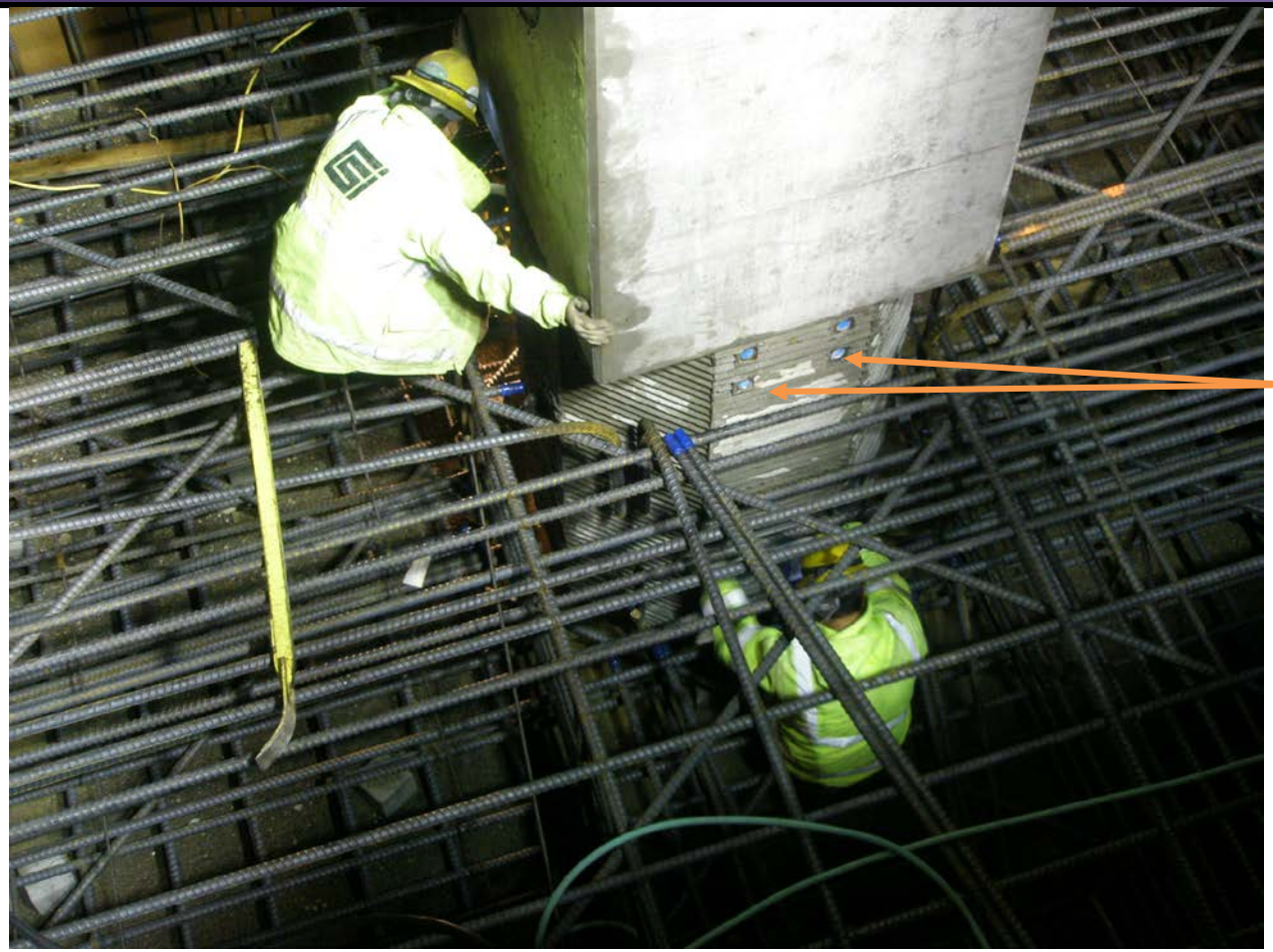
Re-centering,
low-damage connections



Accelerated Bridge Construction

- *Prestressed girders are already pre-fabricated.*
- *Prefabricate bridge bents components too*
- *Pretensioning*
- *Connections are the key*
  - *Ease of assembly (simplicity, speed, tolerances)*
  - *Seismic resistance*

Field Implementation



Tri-State Construction. SR520, Redmond

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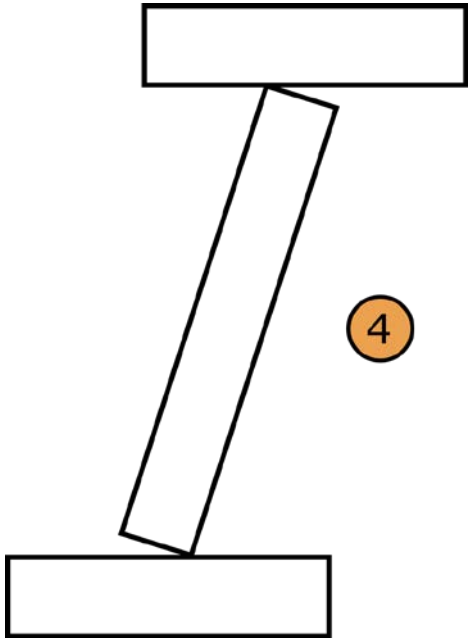
Re-centering Low Damage System

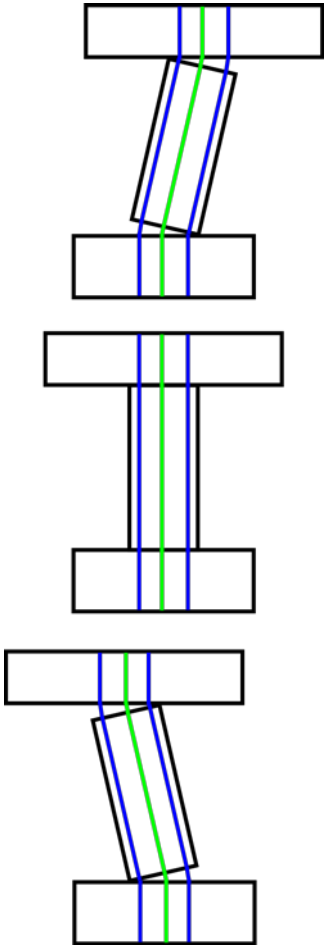
Re-Centering Low Damage System

- *Precast column for fast on-site construction.*
- *Use unbonded prestressing to re-center the column. Rocking minimizes column damage.*
- *Pre- (not post-) tension the column.*
- *Connections:*
  - *Bottom: Wet socket*
  - *Top: New ("Dry Socket")*



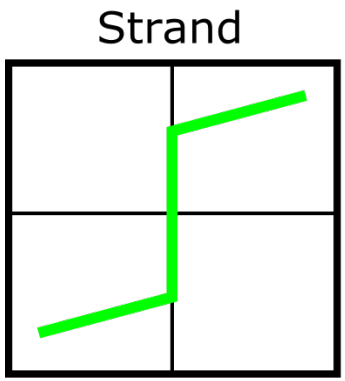
Re-Centering Low Damage System

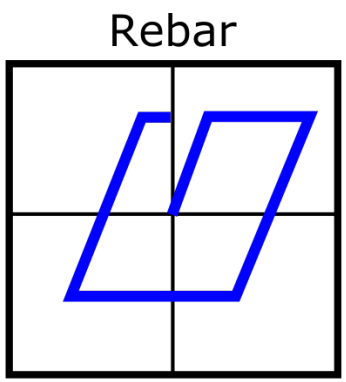
Partially Unbonded Pre-tensioning

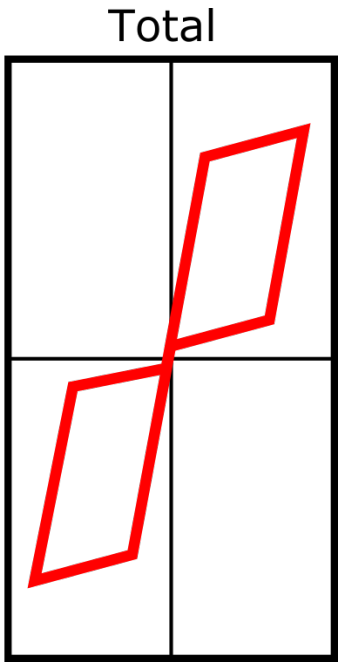


Strand: Stays elastic, provides re-centering force

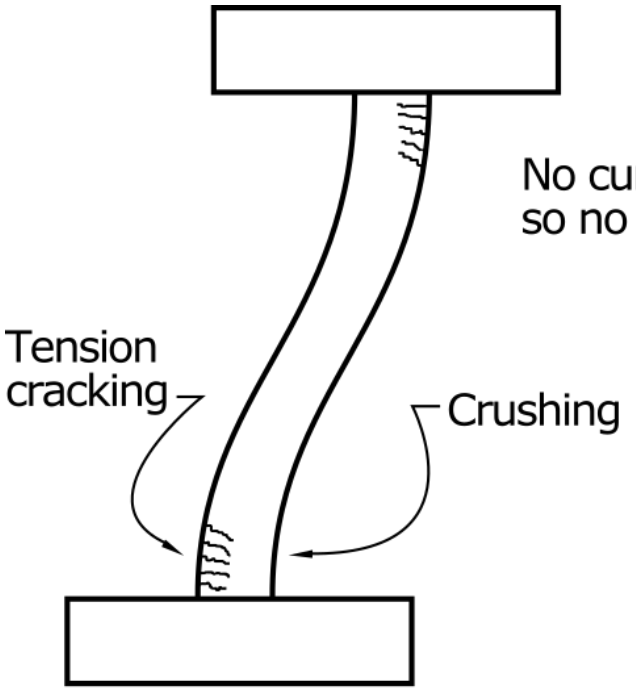
Rebar: Yields and dissipates energy

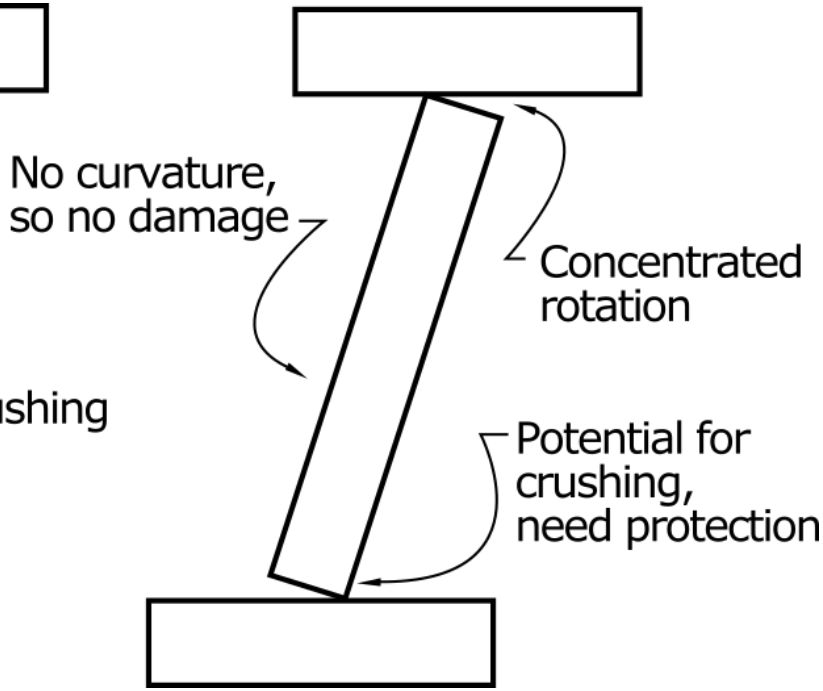






Low-Damage, Rocking Behavior

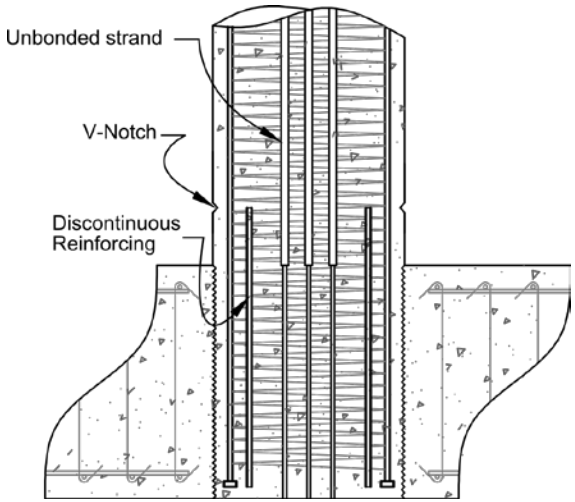




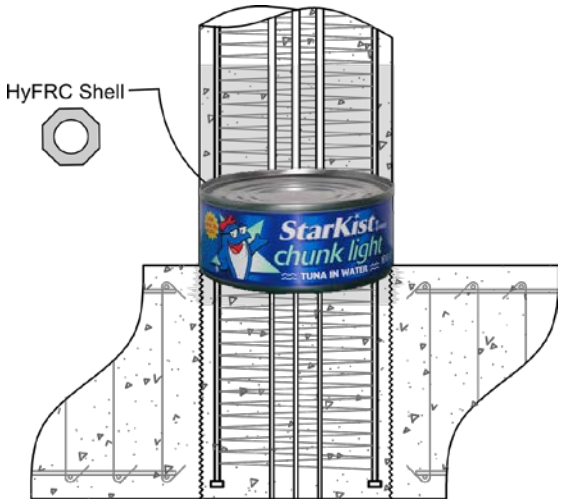
Bending: Tension cracks and compression crushing inevitable

Rocking: High contact stresses

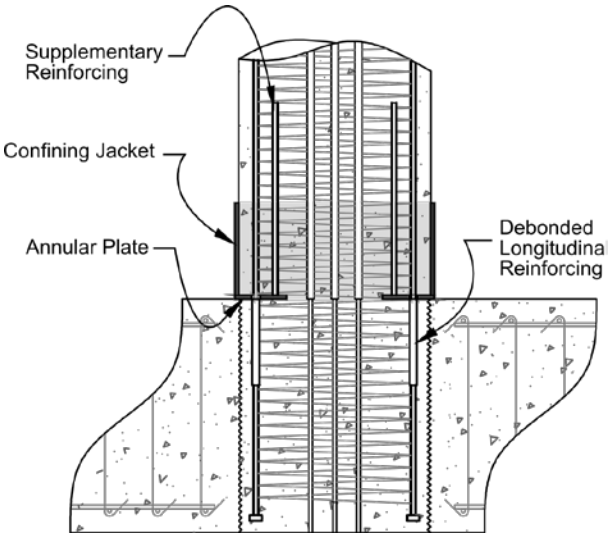
Detailing Strategies



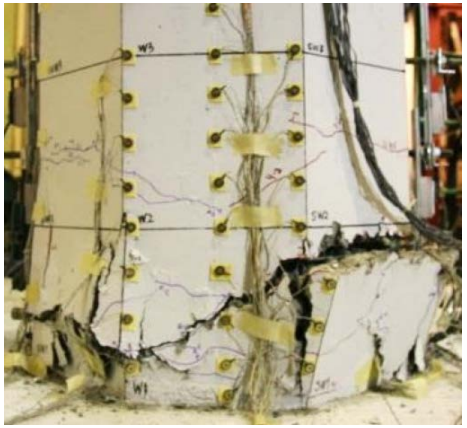
Conventional concrete only

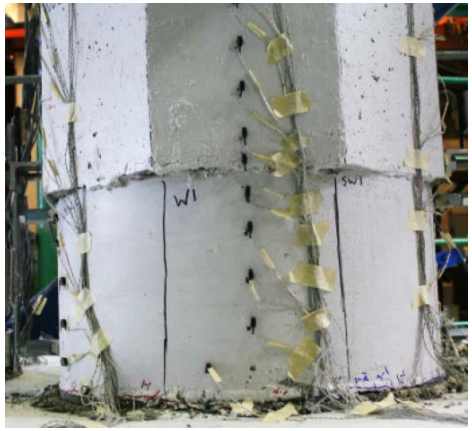


HyFRC in plastic hinge region

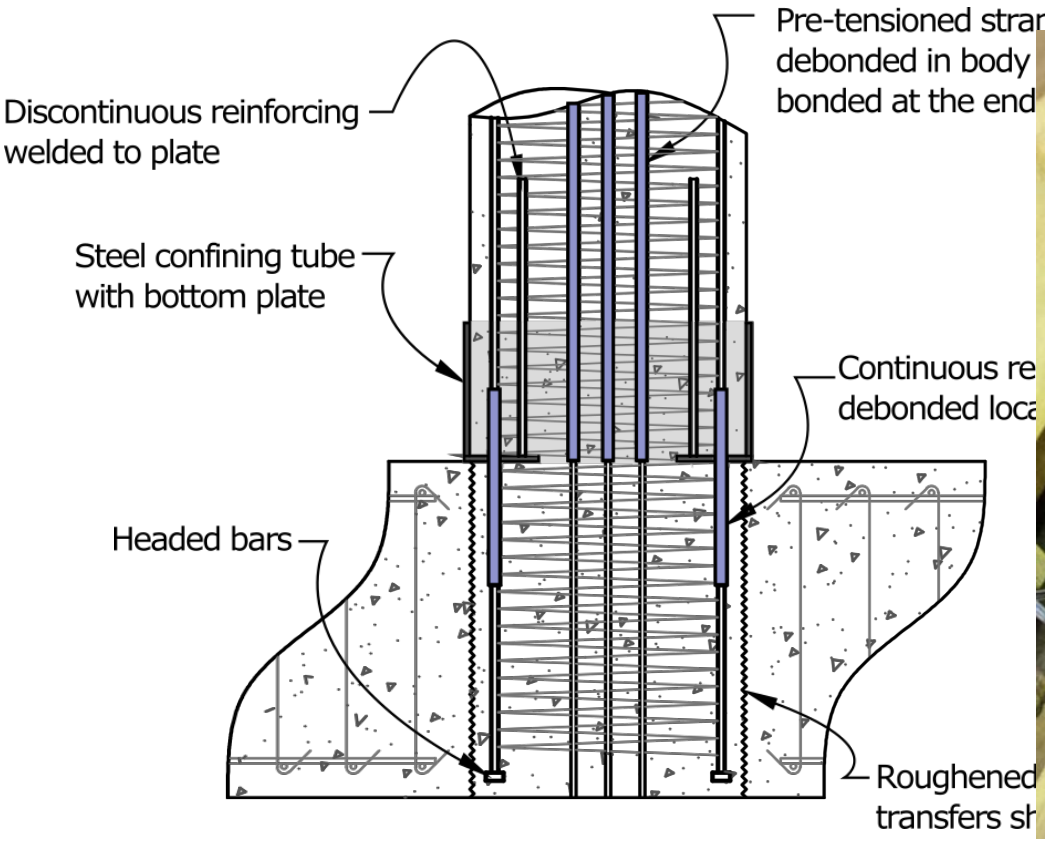


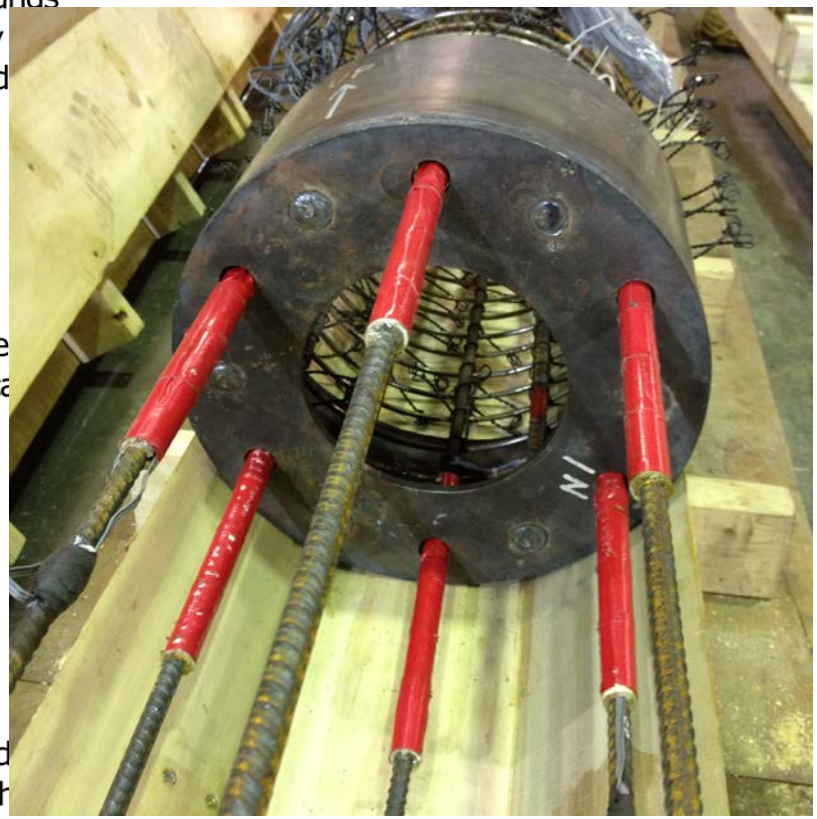
Steel tube confinement



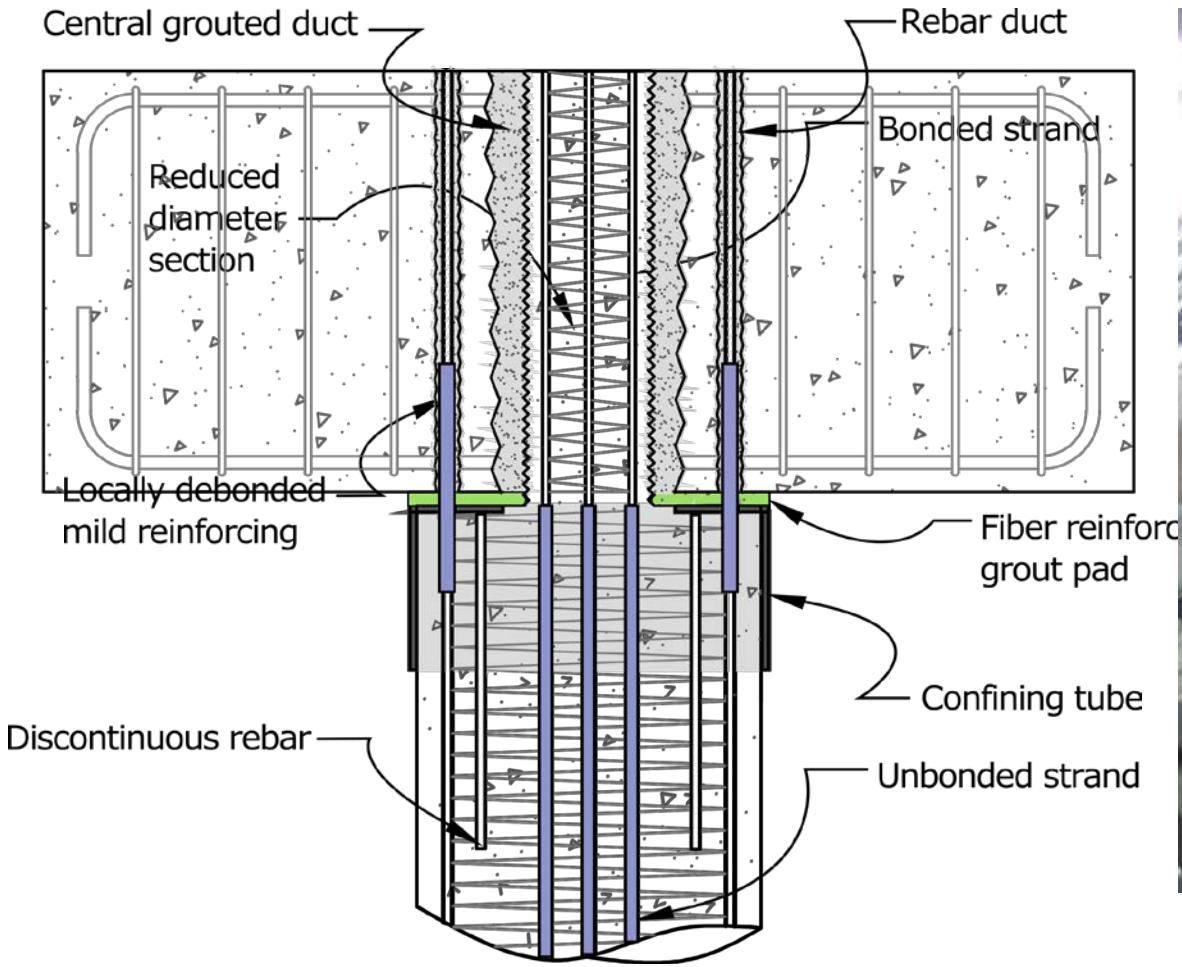


"Wet Socket" Spread Footing Connection



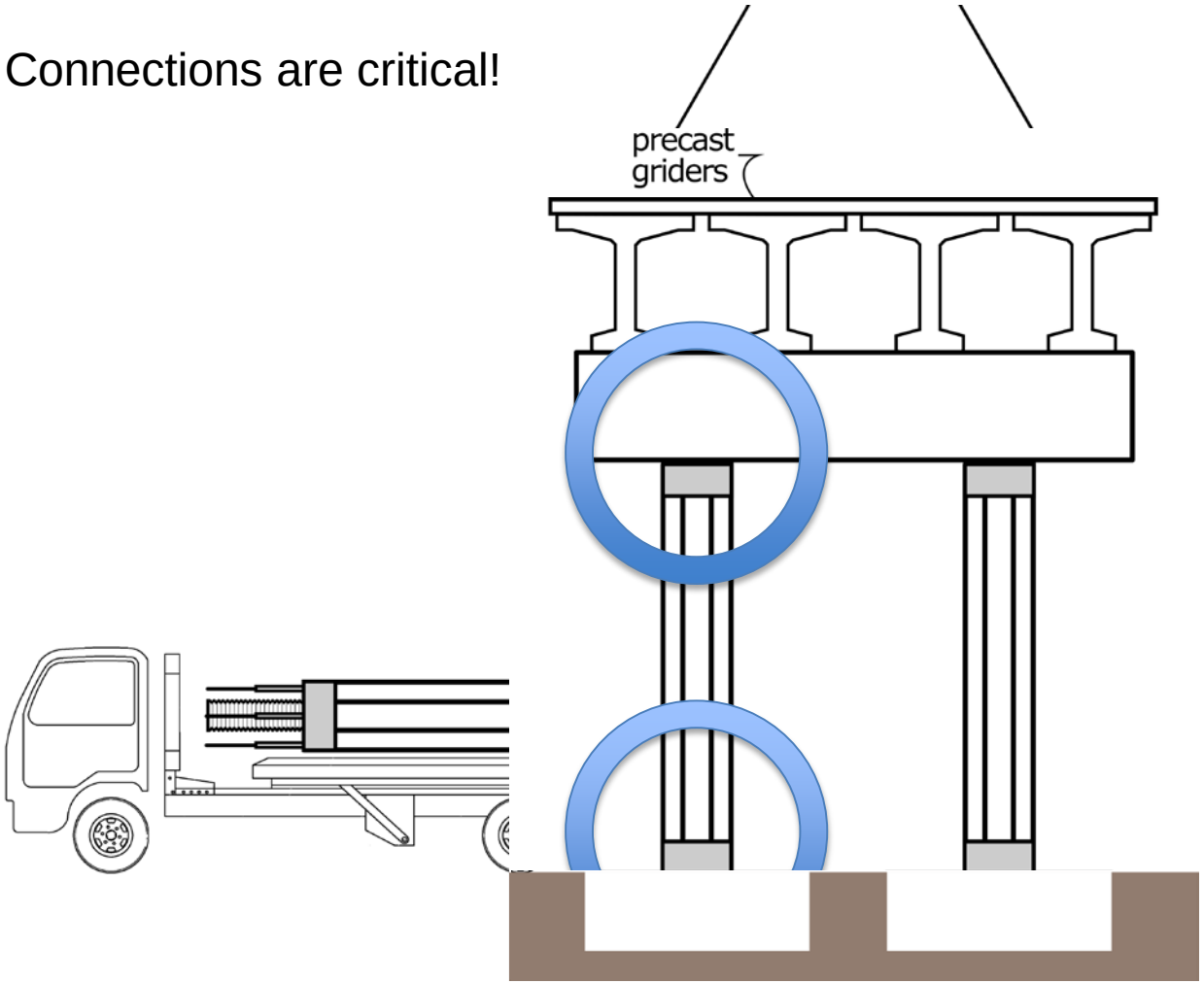


"Grouted-Bar-Socket" Cap Beam Connection



Construction Sequence

Connections are critical!



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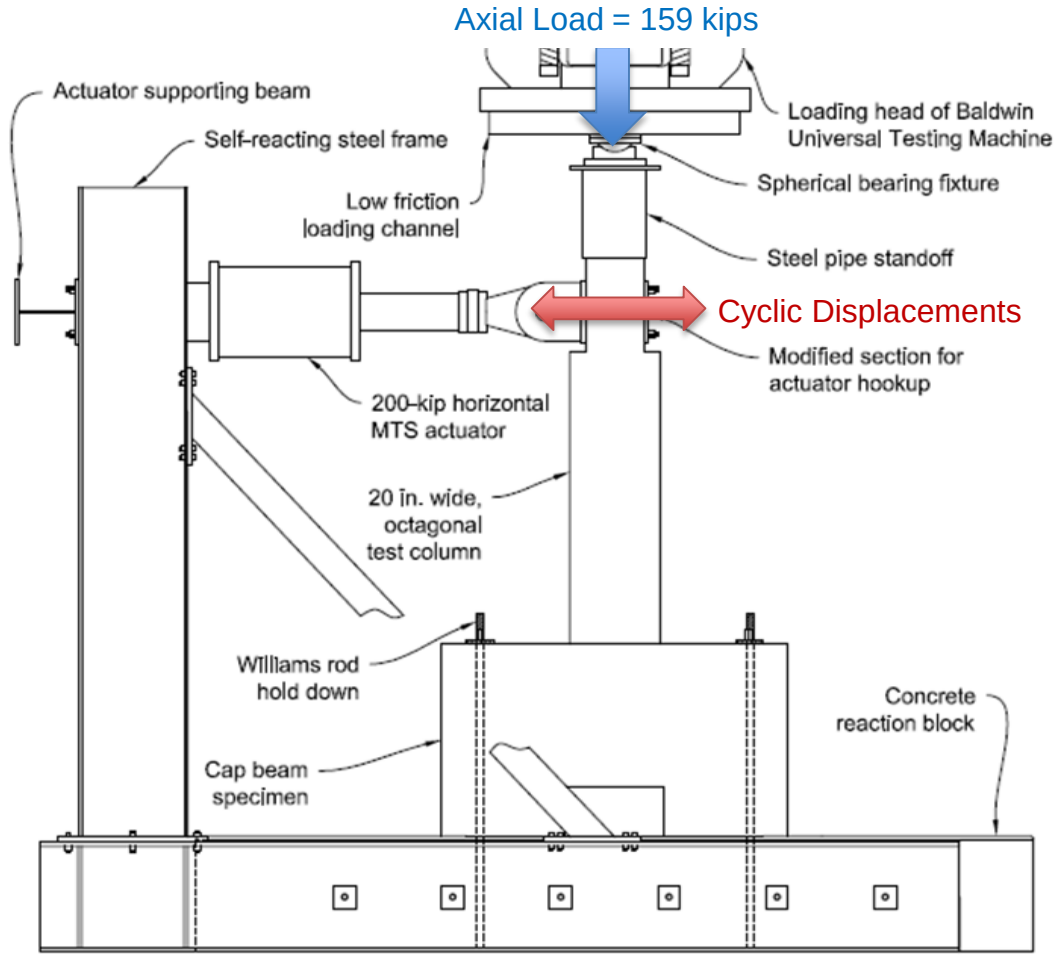
Subassembly Tests

Test Configuration

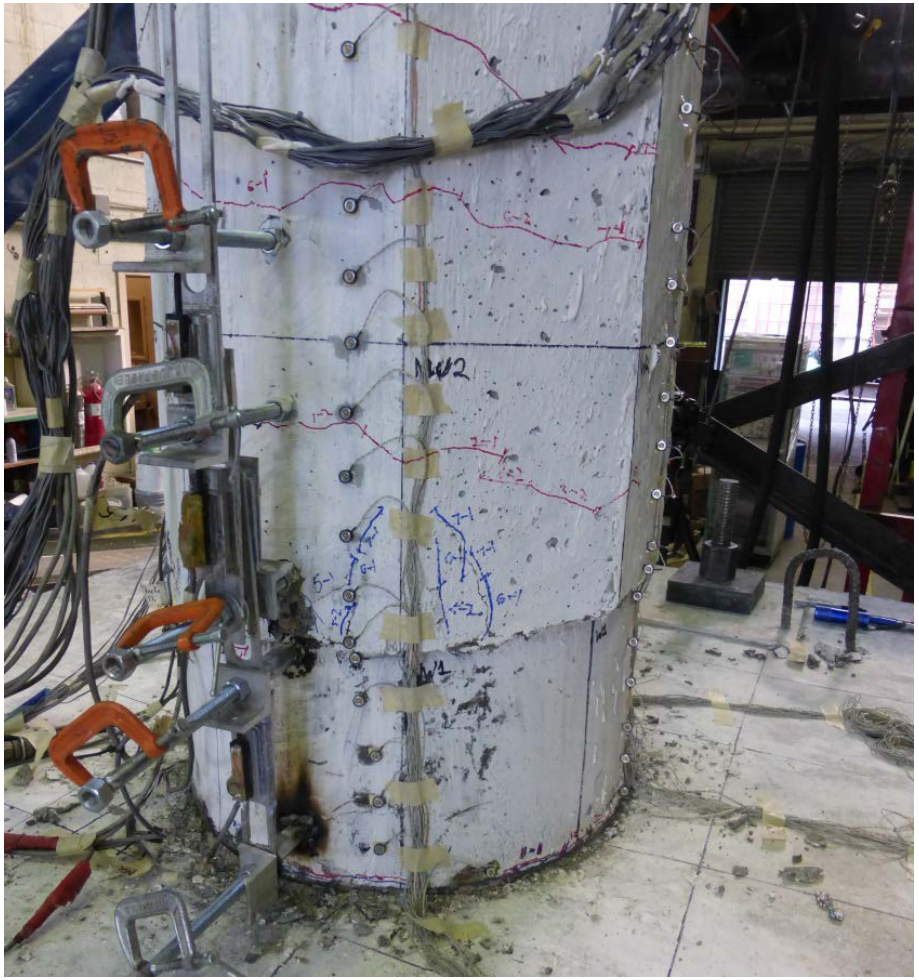


Observations

After 10% drift:

- No concrete damage,
- No footing damage,
- No cap beam damage.

- Rebars broken (θ = 6%)
- Strand yielded (θ = 3%)

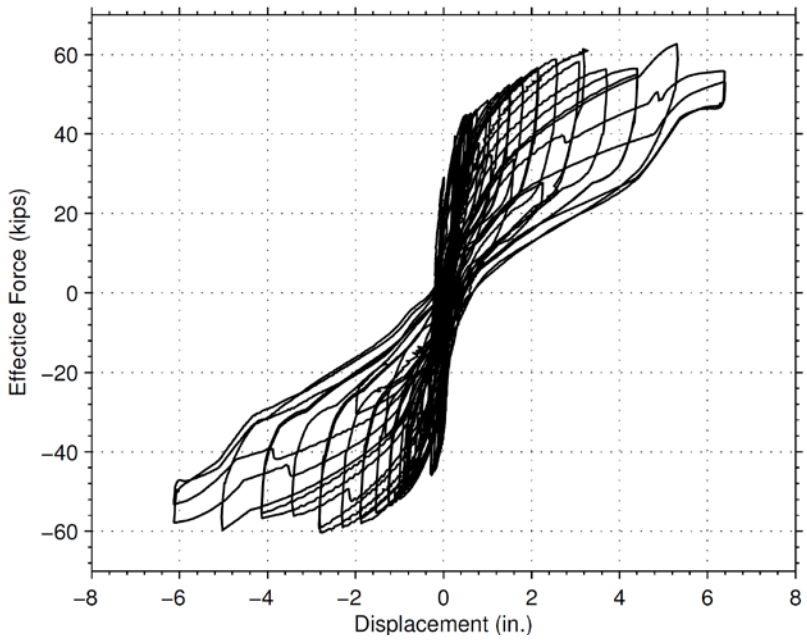


Column Performance

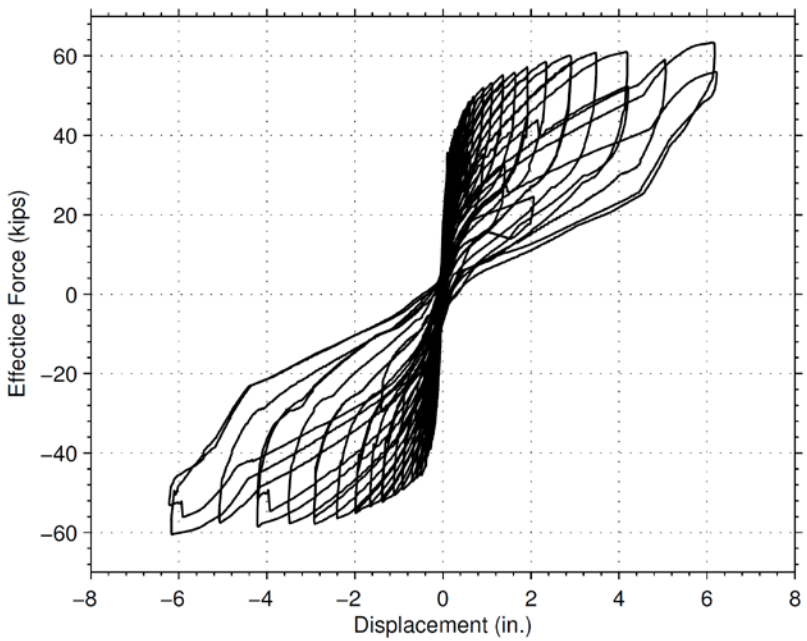
After 10% drift:

- Limited strength degradation (over 80% peak strength)
- Returns to within 0.1 d_{peak} residual displacement

Spread Footing Rocking Connection

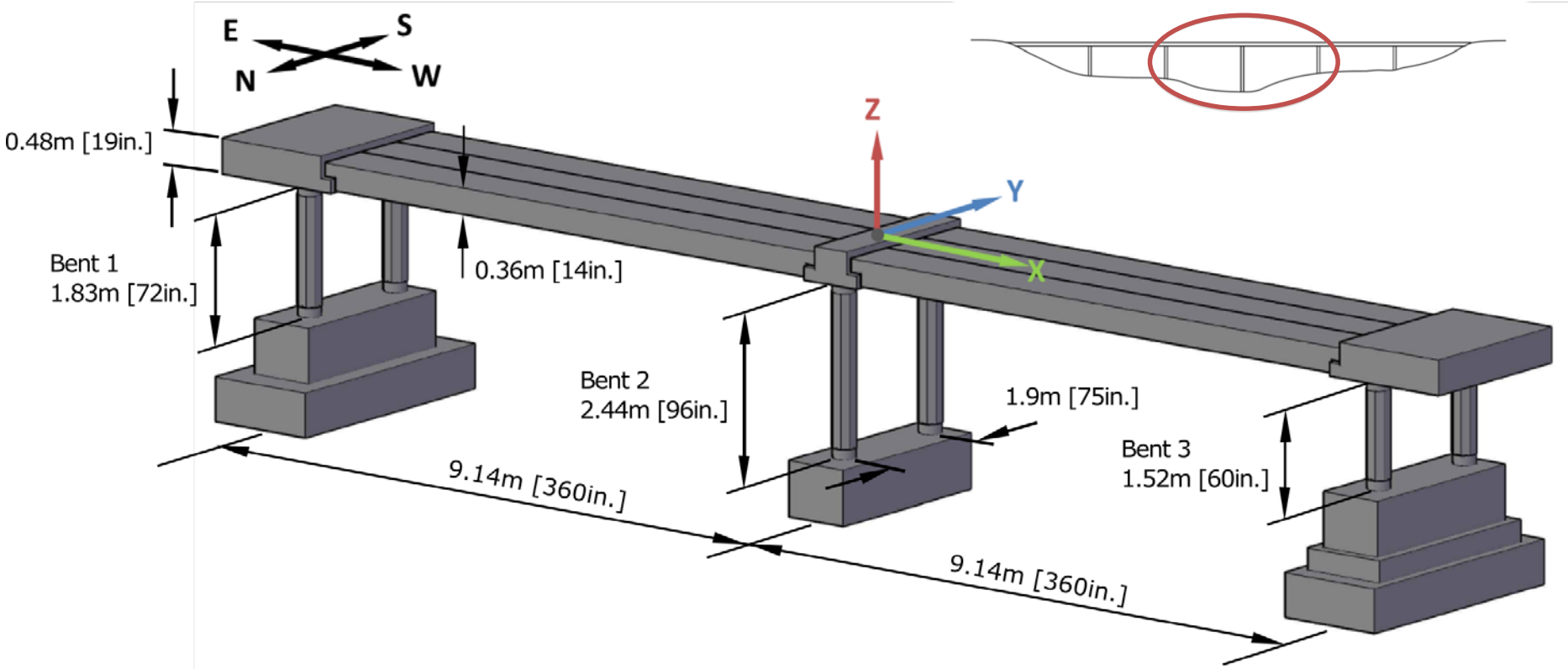


Cap Beam Rocking Connection



Specimen Dimensions

- Two-span portion of a typical bridge in the western united states supported by two column bents on drilled shafts.



2005 RC Bridge Motion 19 (220% Design Level)
1994 Northridge - Century City CC North (PGA=1.66g)

2005 RC Bridge Motion 19 (220% Design Level)
1994 Northridge - Century City CC North (PGA=1.66g)

- Bent 3 columns fully spalled, spiral fracture, bar buckling.
- Load over bent 3 was removed due to safety concerns.

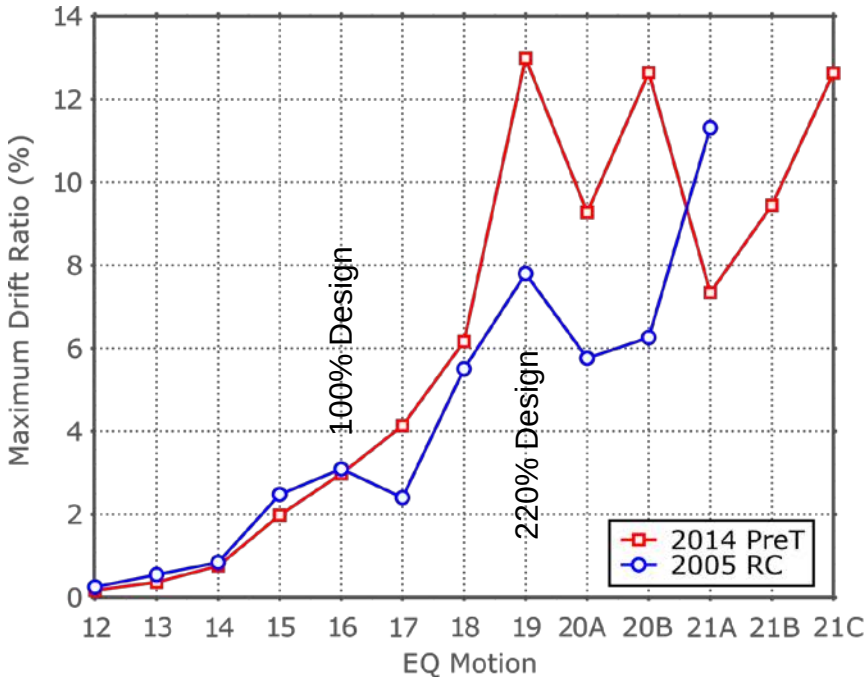
2014 PreT Bridge Motion 19 (220% Design Level)
1994 Northridge - Century City CC North (PGA=1.66g)

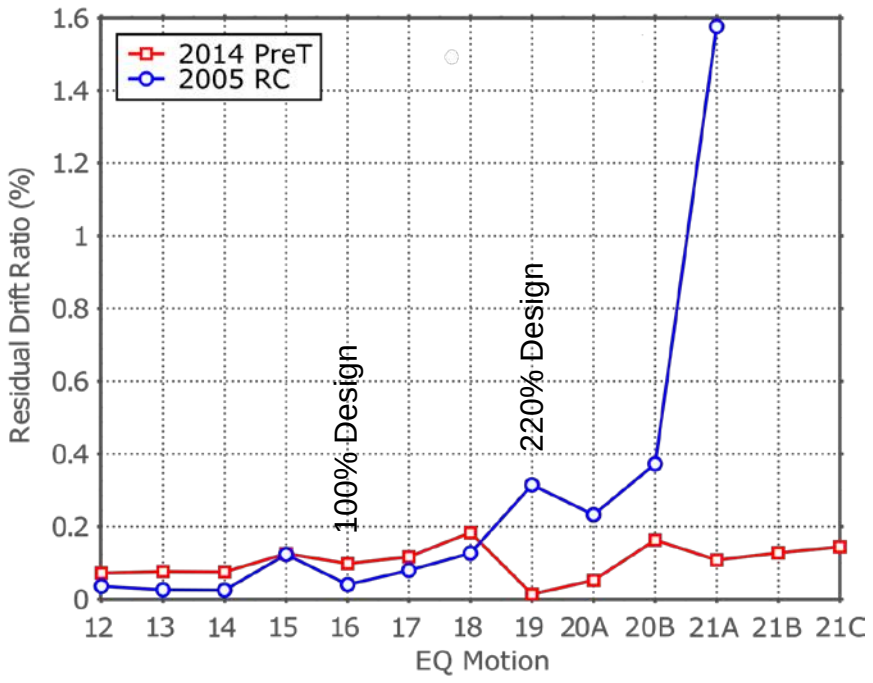
2005 RC Bridge Motion 19 (220% Design Level)
1994 Northridge - Century City CC North (PGA=1.66g)

- Hairline horizontal cracks (3 in total) minor flaking at steel tube,
- rebar fracture, bulging of steel confining jackets.

Shake Table Test → **2014 PreT Bridge Motion 21C**

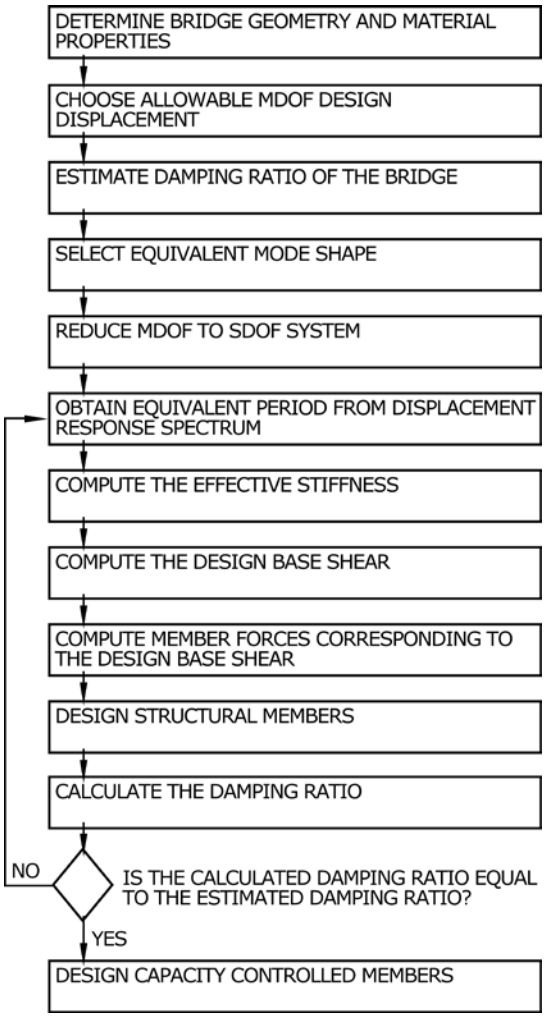
Column Performance





Design

Displacement-Based Dessign



DETERMINE MAXIMUM INITIAL PRESTRESSING FORCE

Strands should remain elastic at design level drift
Strands should not fracture at maximum credible drift

CHOOSE MINIMUM RECENTERING RATIO

System recenters within allowable residual displacements

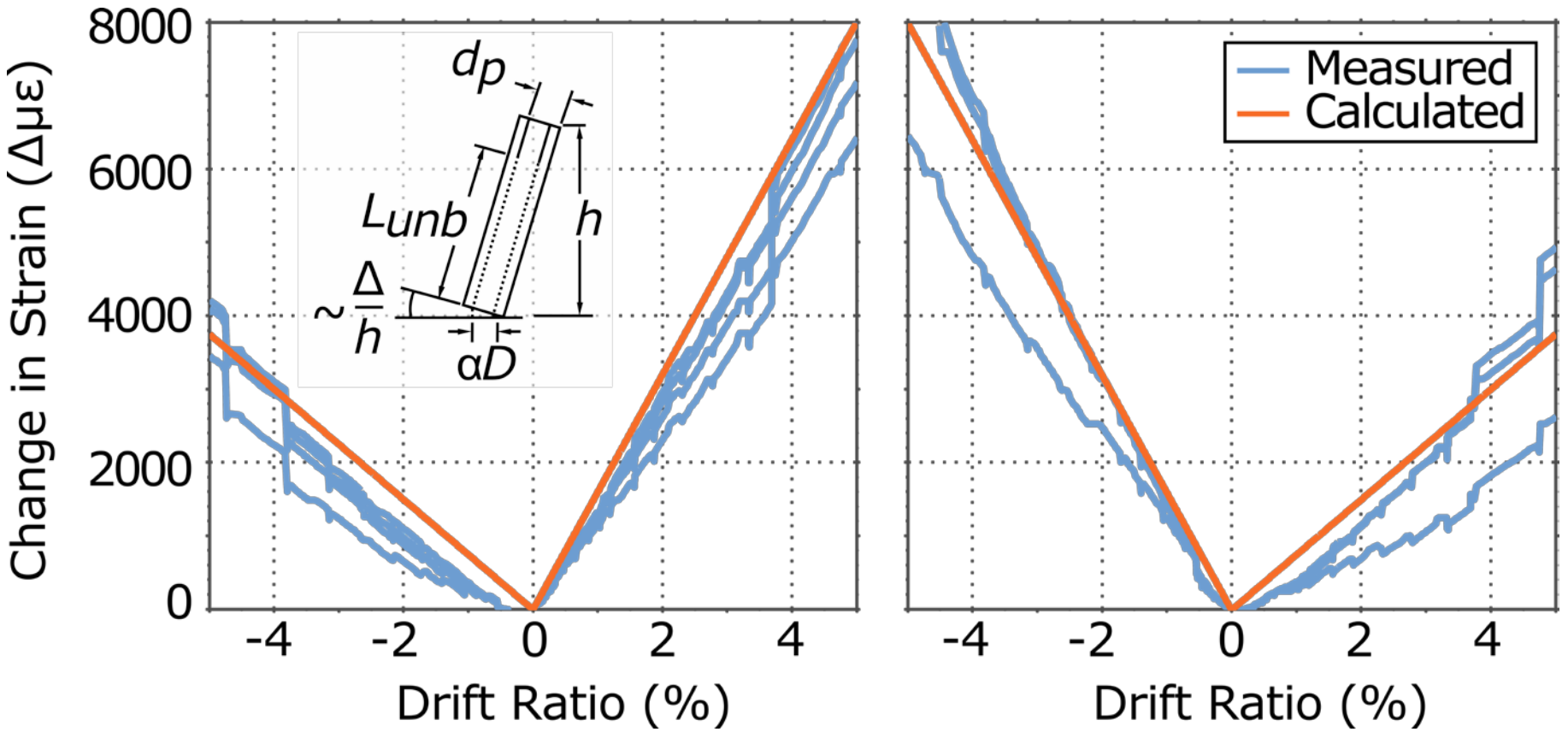
DETERMINE MINIMUM UNBONDED LENGTH OF LONGITUDINAL DEFORMED BAR REINFORCEMENT

Reinforcement should not fracture at maximum credible drift

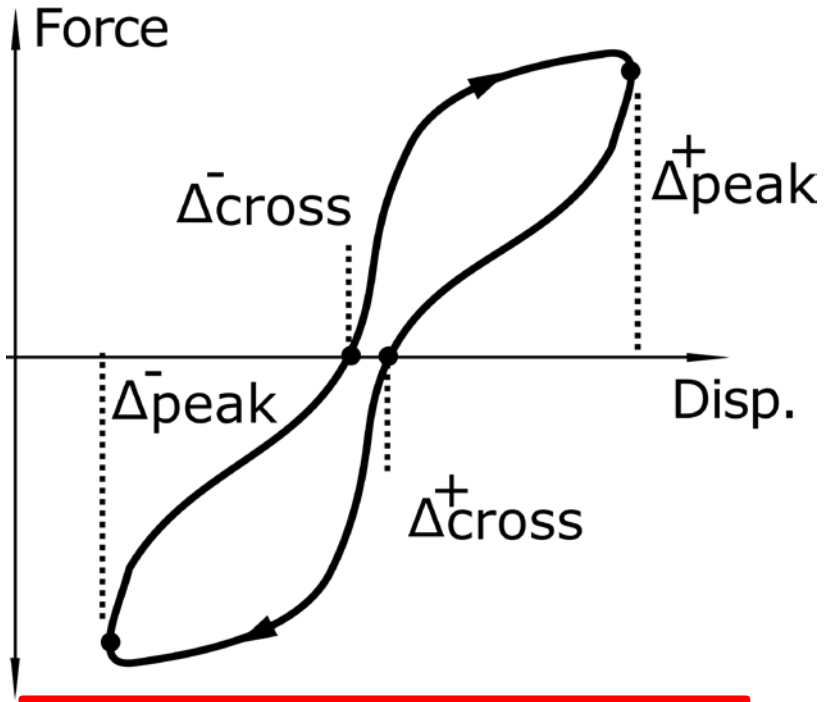
DETAIL PLASTIC HINGE REGION FOR CONCENTRATED ROTATIONS AT COLUMN ENDS

No damage to column concrete at design level drift
Minor damage to column concrete at maximum credible drift

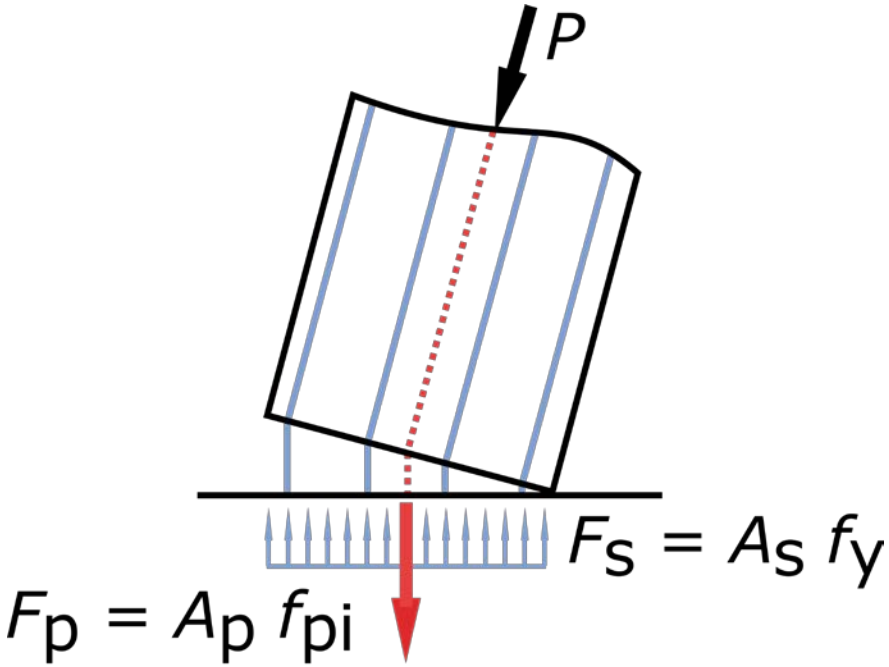
Strand Strain versus Drift



NCOD

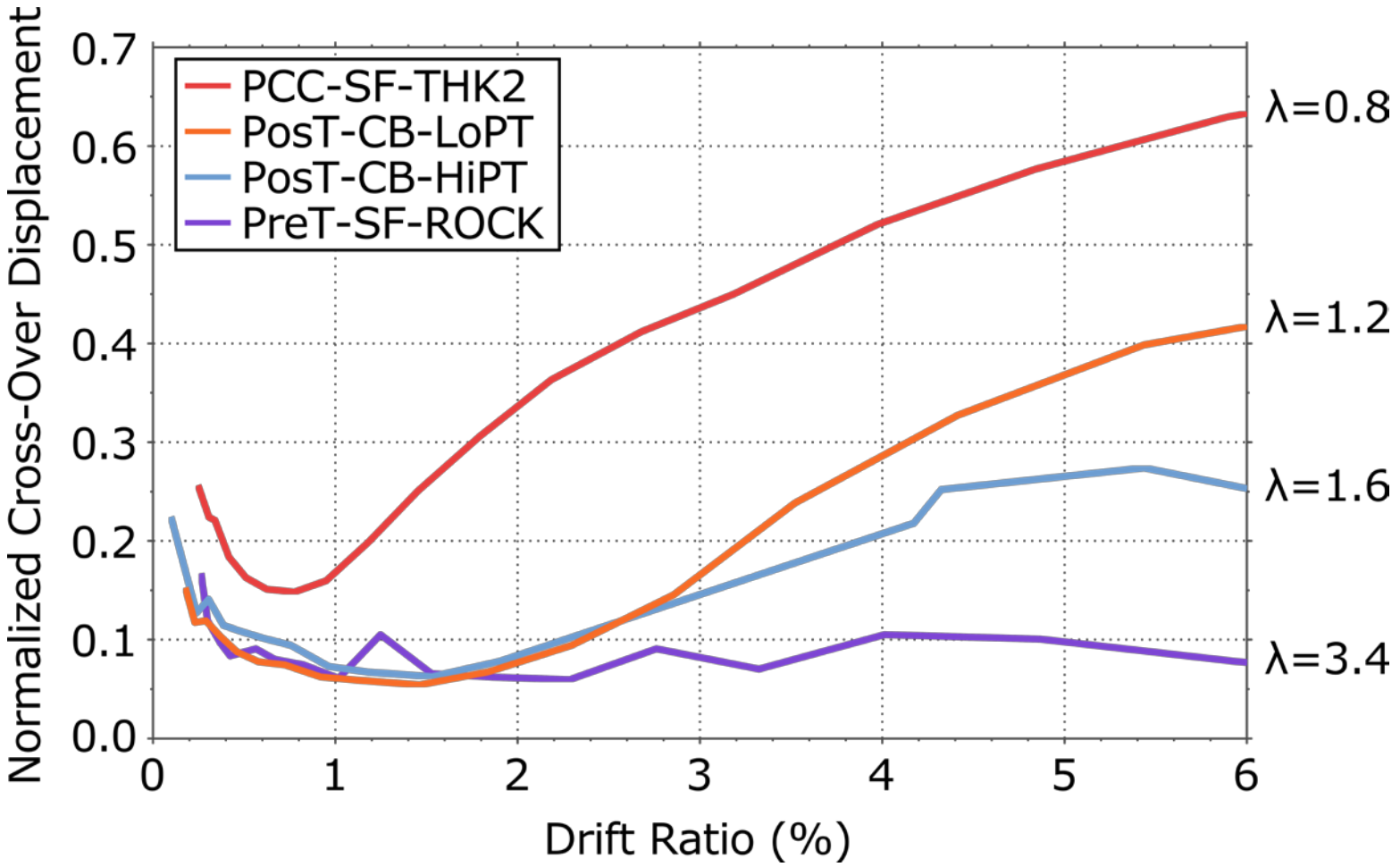


$$NCOD = \frac{\Delta^{+}_{cross} - \Delta^{-}_{cross}}{\Delta^{+}_{peak} - \Delta^{-}_{peak}}$$

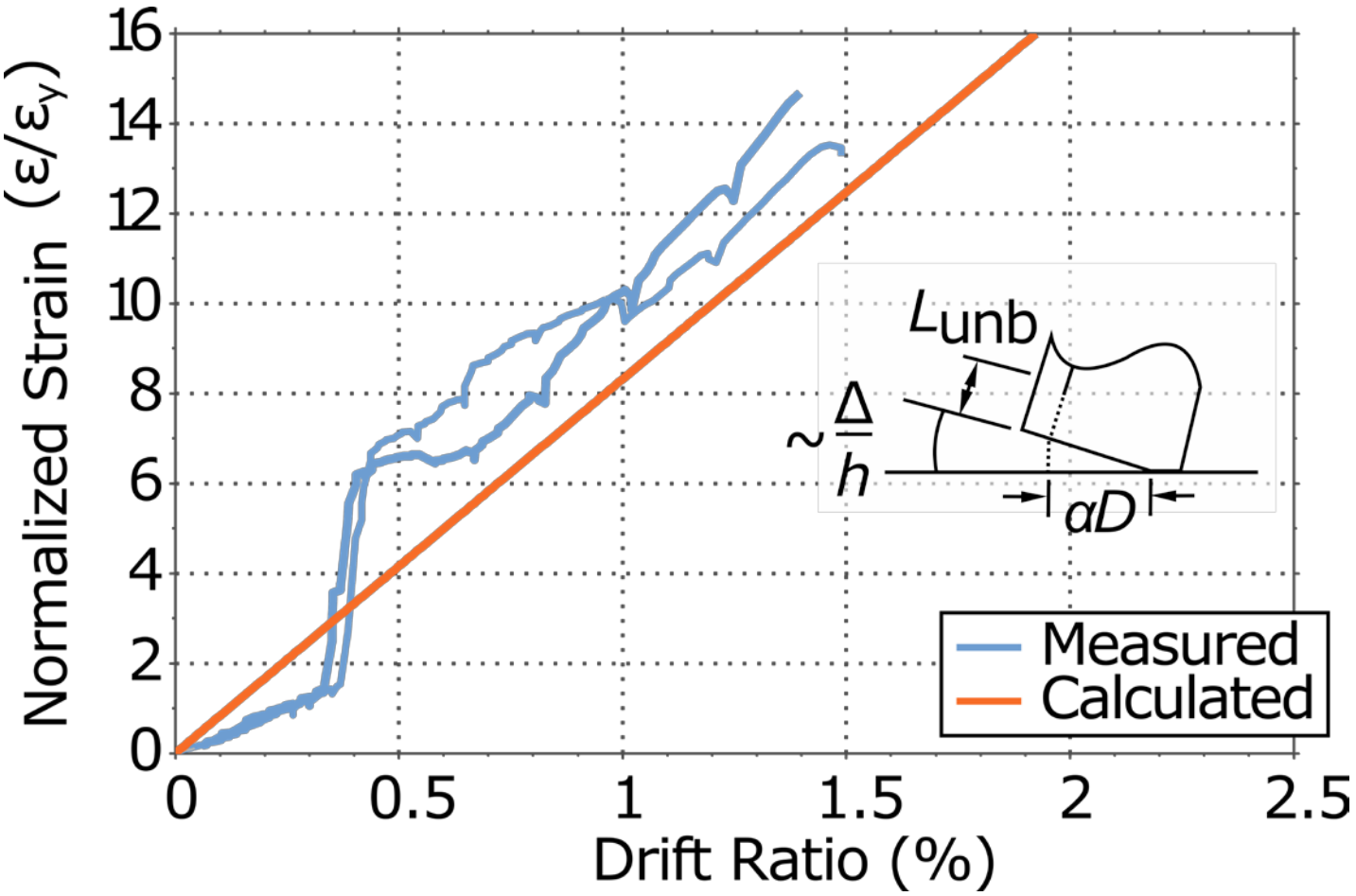


$$\lambda = \frac{P + A_p f_{pi}}{A_s f_y}$$

NCOD versus drift



Rebar Strain versus Drift



Conclusions

Accelerated Construction

- Easy, rapid assembly on site.
- Precast cap beam saves a lot of time.
- Critical components (e.g. prestressing) done in plant under good QC.
- No Post-Tensioning needed on site.
- No anchorages susceptible to corrosion.
- Uses only common construction materials.

Improved Seismic Performance

- Zero residual drift even after 13% peak drift.
- Concrete damage only cosmetic even after 13% drift.
- Bridge safe for emergency vehicles after earthquake with pga = 1.66 g (Motion 19).
- Strand remained elastic to 3% drift, as designed. (Could go higher if desired.)
- First rebar fracture at 6 – 7% % drift, as designed. (Could go higher if desired.)

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Thank You