Design Strategy to Minimize Seismic Residual Displacements and Damage in a New ABC Bridge Bent

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Acknowledgements

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NEES

DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

PEER
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

ABC UTC

Outline

1. Pre-Tensioned, Rocking Bent System
2. Experimental Performance
3. Design Procedure
4. Conclusions

System Objectives

Accelerate Construction

Eliminate Residual Displacements

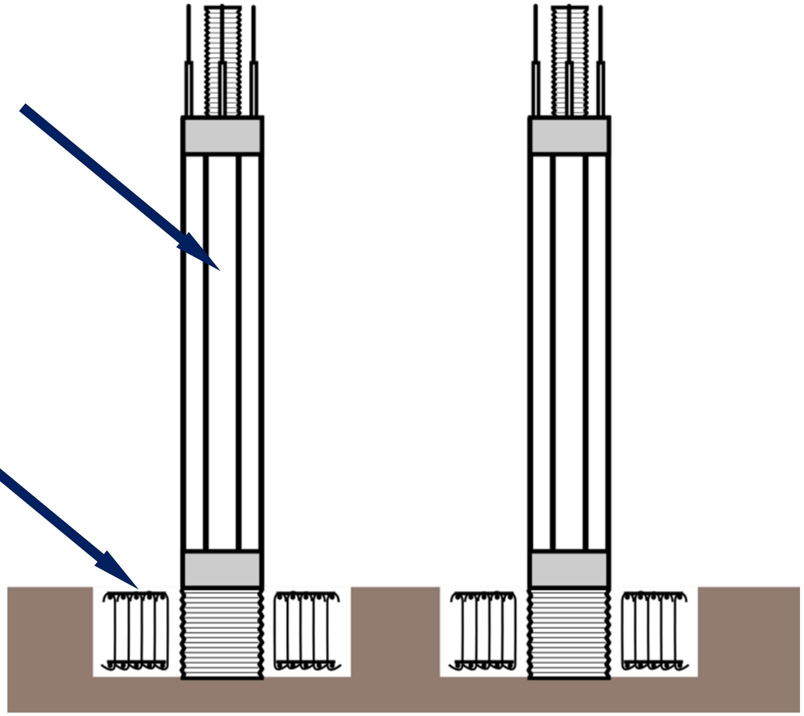
Reduce Column Damage

Accelerate Construction

Accelerate Construction

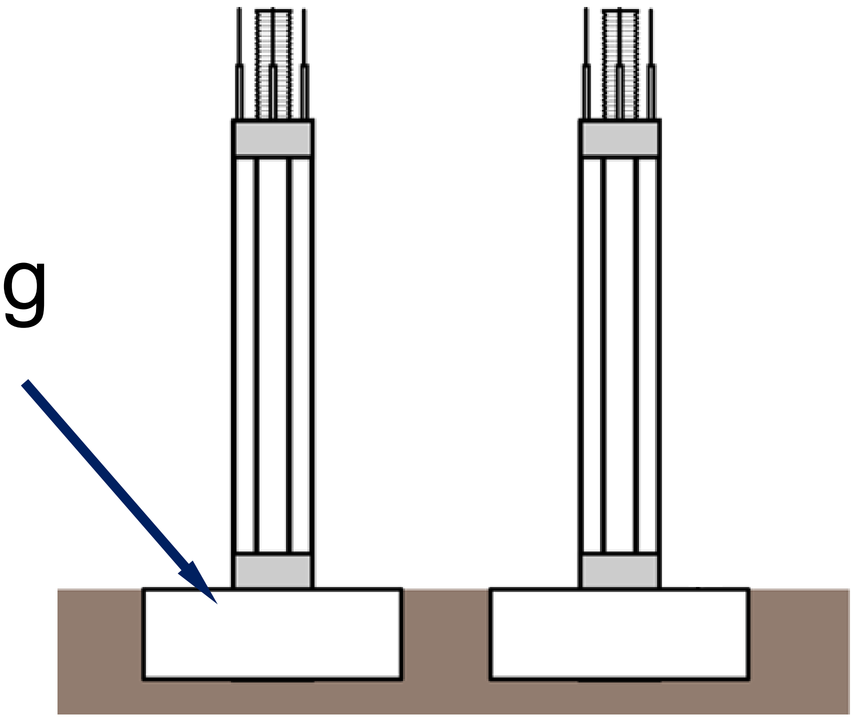
Pretensioned column

Footing reinforcement placed around column



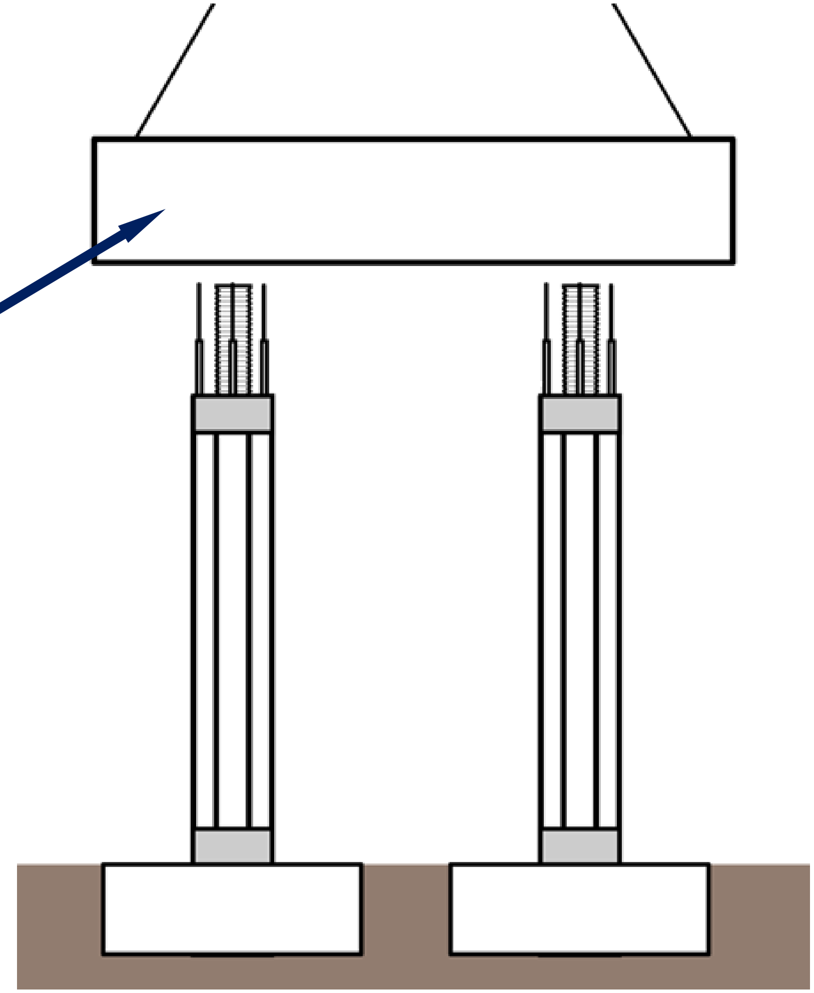
Accelerate Construction

Cast-in-place footing



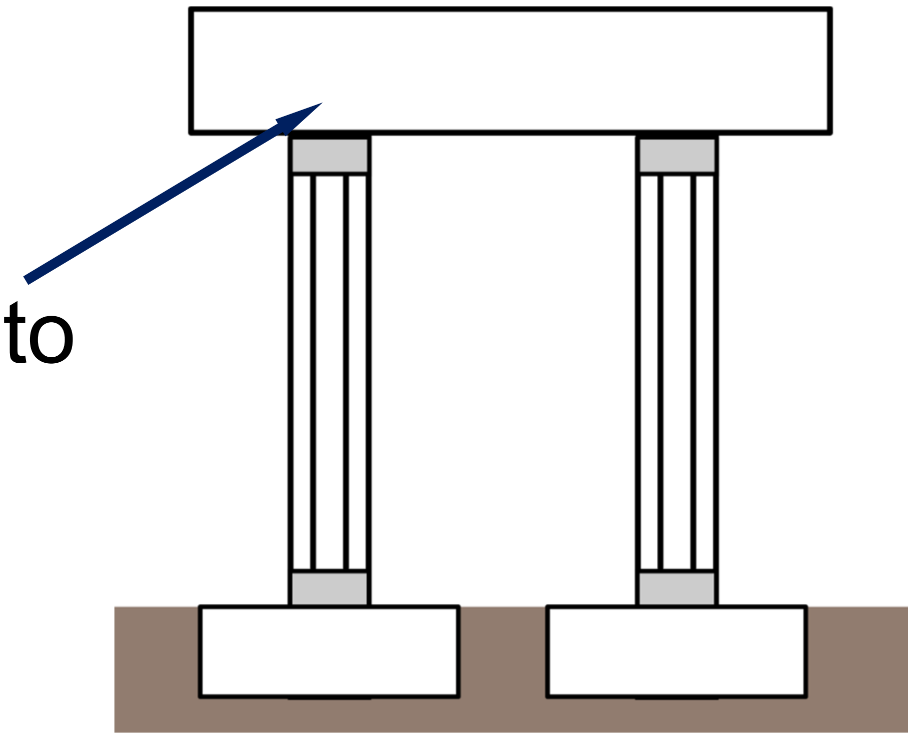
Accelerate Construction

Precast cap beam



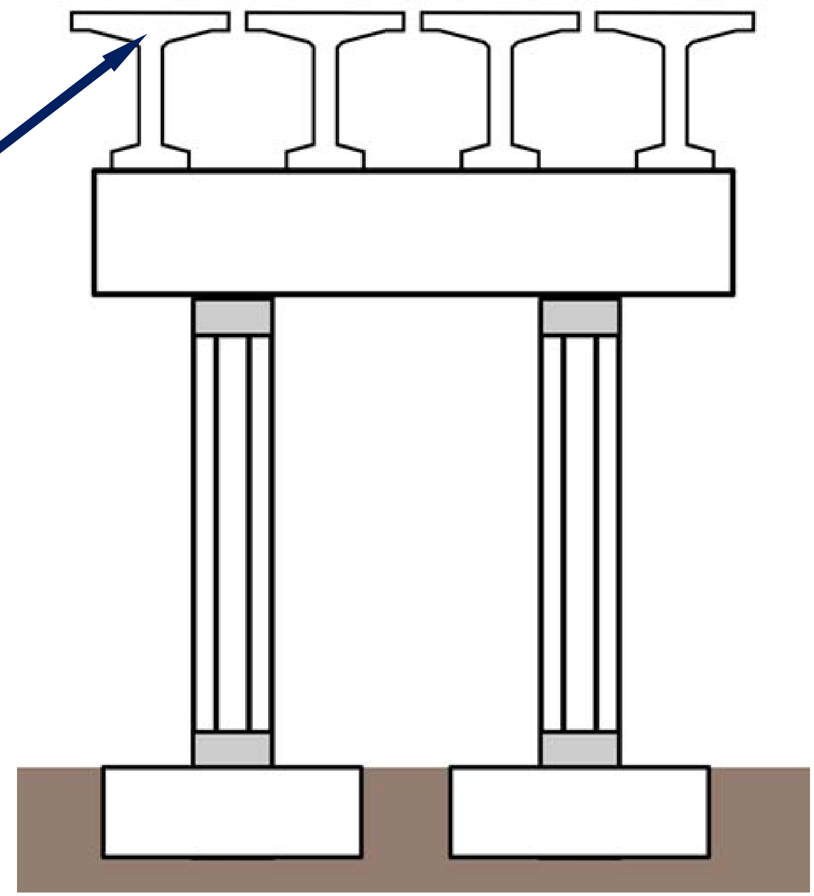
Accelerate Construction

Bars and column segment grouted into ducts



Accelerate Construction

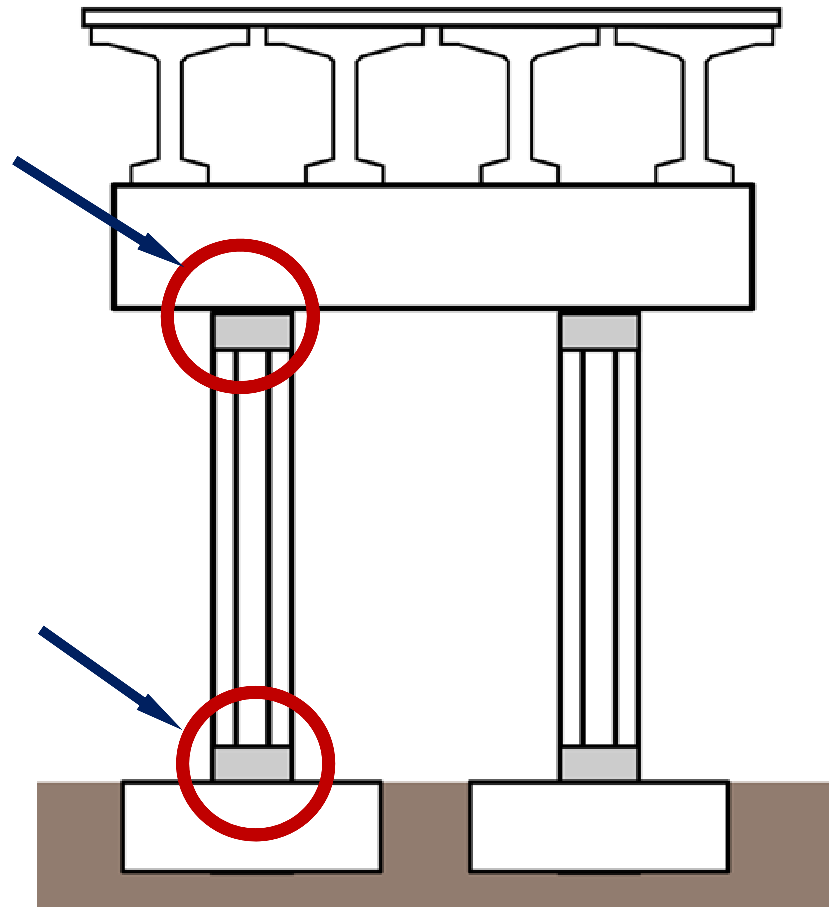
Precast girders



Accelerate Construction

Grouted duct connection

“Wet” socket connection



“Wet” Socket Connection

Grouted Duct Connection

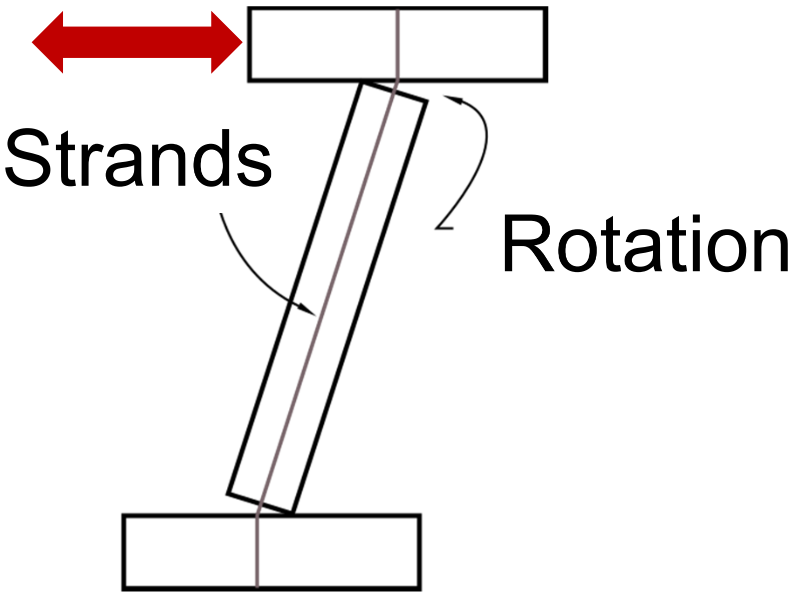
Eliminate Residual Displacements

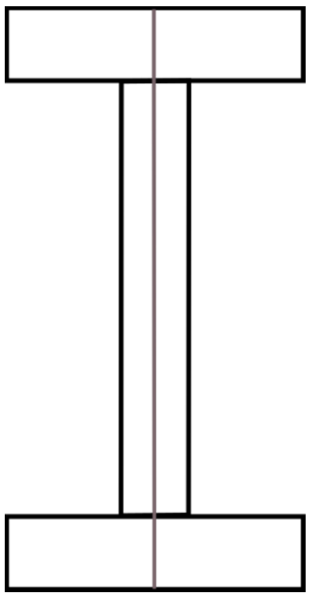
During Earthquake

Strands elongate
due to joint opening.

After Earthquake

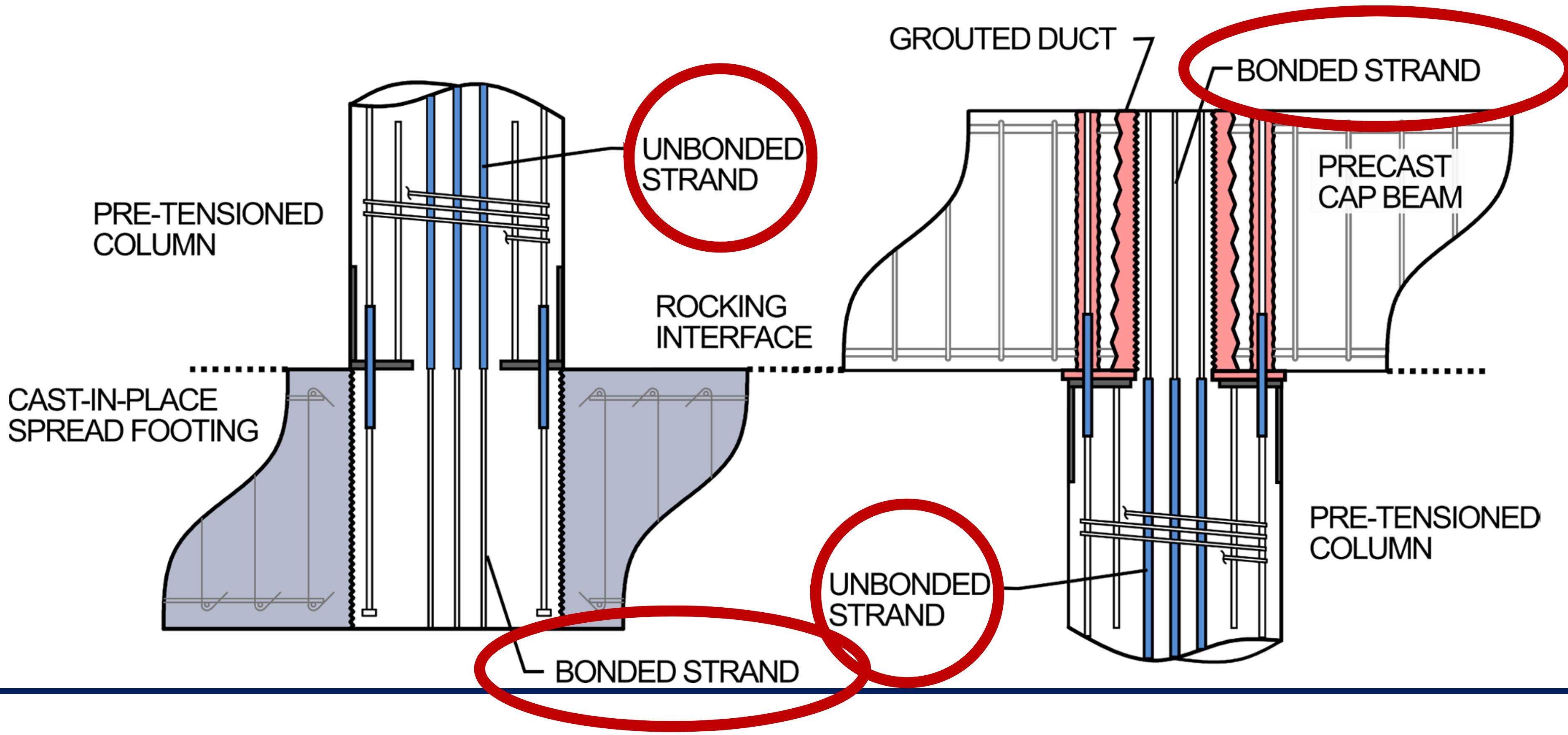
Force in strands
rights the column.





Eliminate Residual Displacements

Pretensioned strands bonded within footing and cap beam.



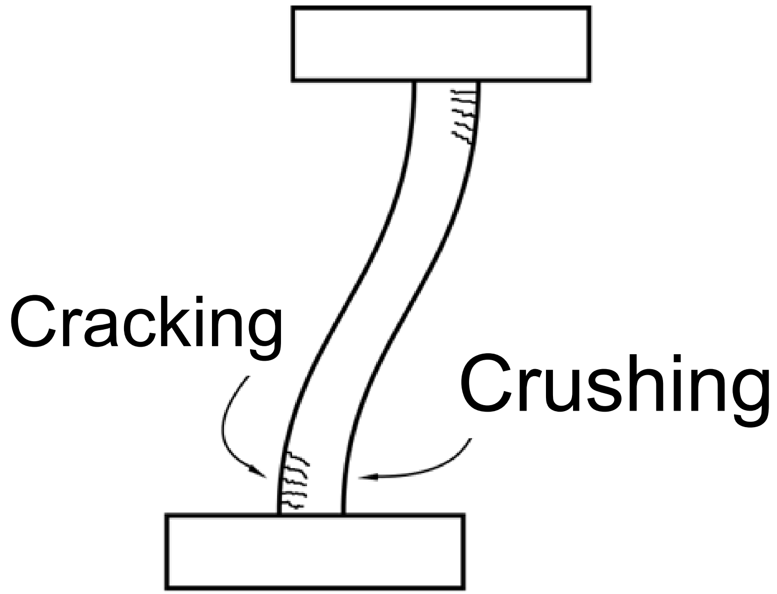
Reduce Column Damage

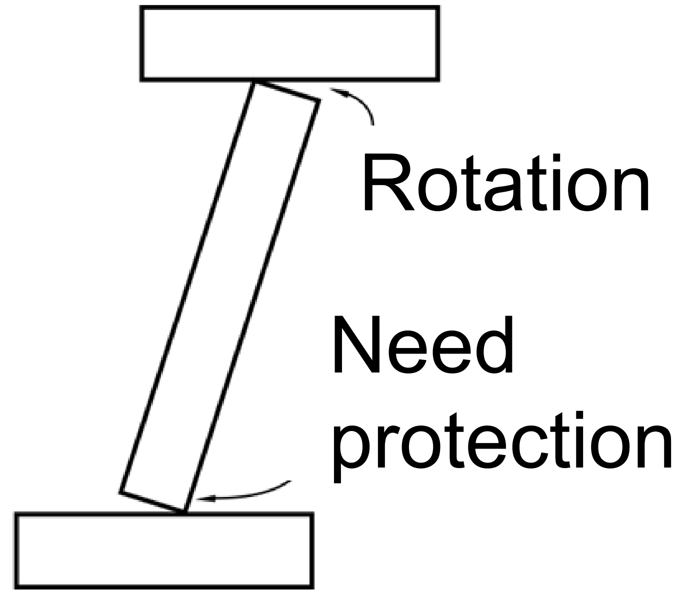
Bending

Tension cracks and compression crushing

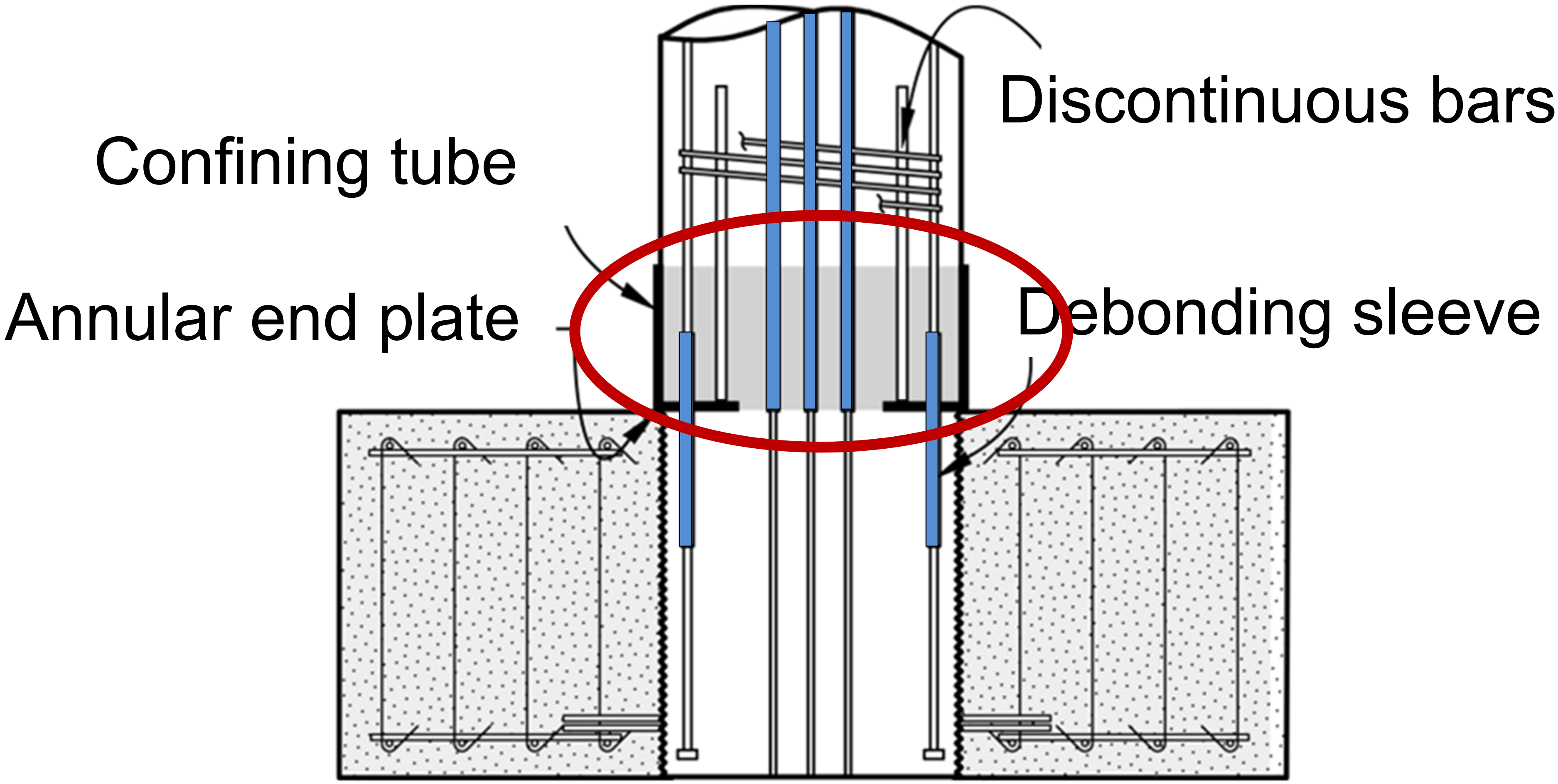
Rocking

High contact stresses





Reduce Column Damage



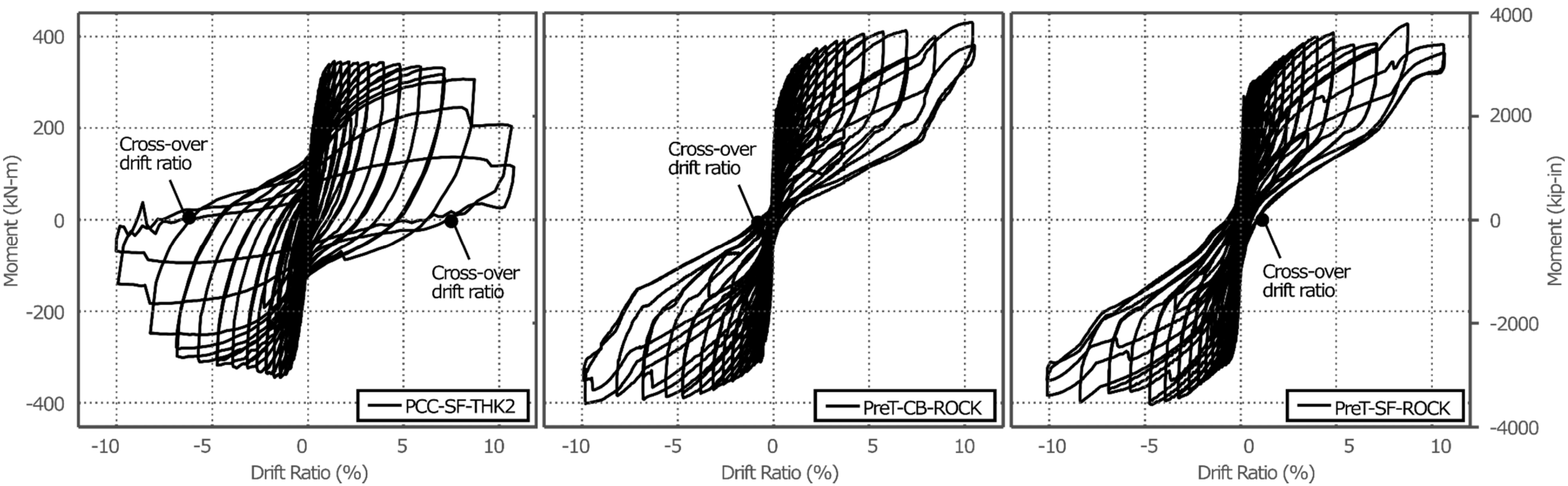
Experimental Performance

Subassembly Tests

Minimal strength degradation & cross-over displacements

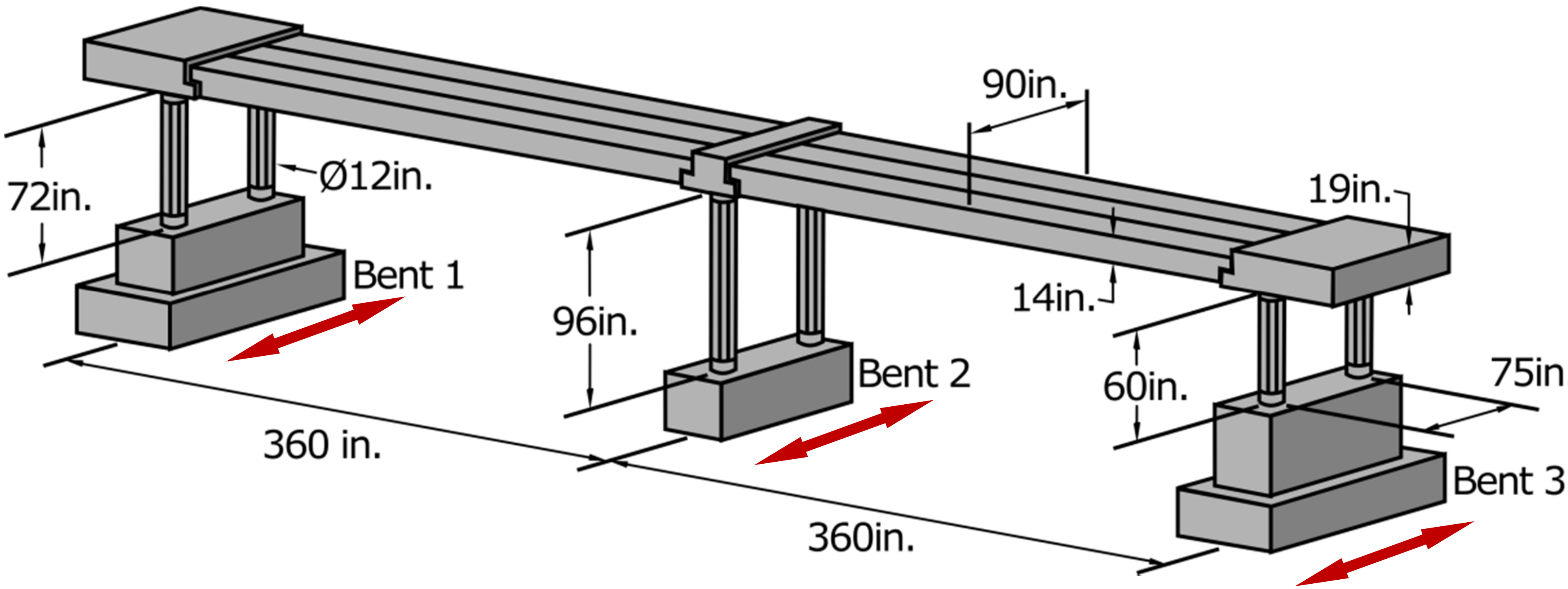
Conventional

Pretensioned, Rocking



Shake Table Tests

Specimen designed to match previously tested RC bridge



1994 Northridge EQ (221% Design)

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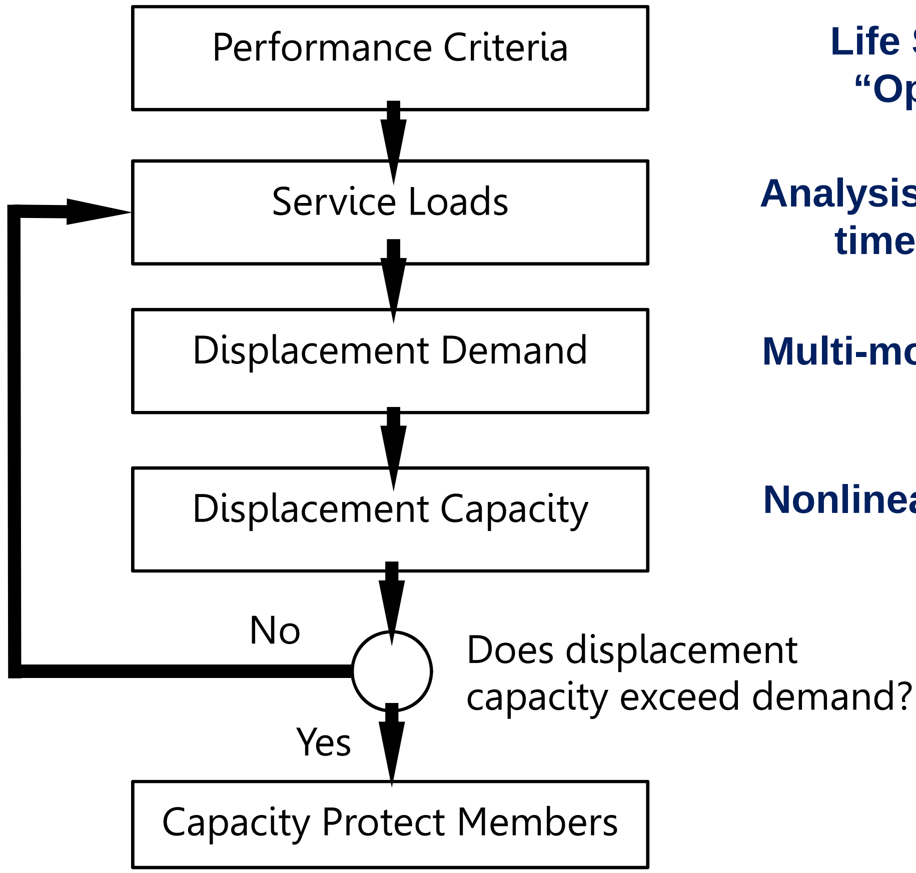
Design Process

AASHTO Displacement Based Design Methodology (SDC D)



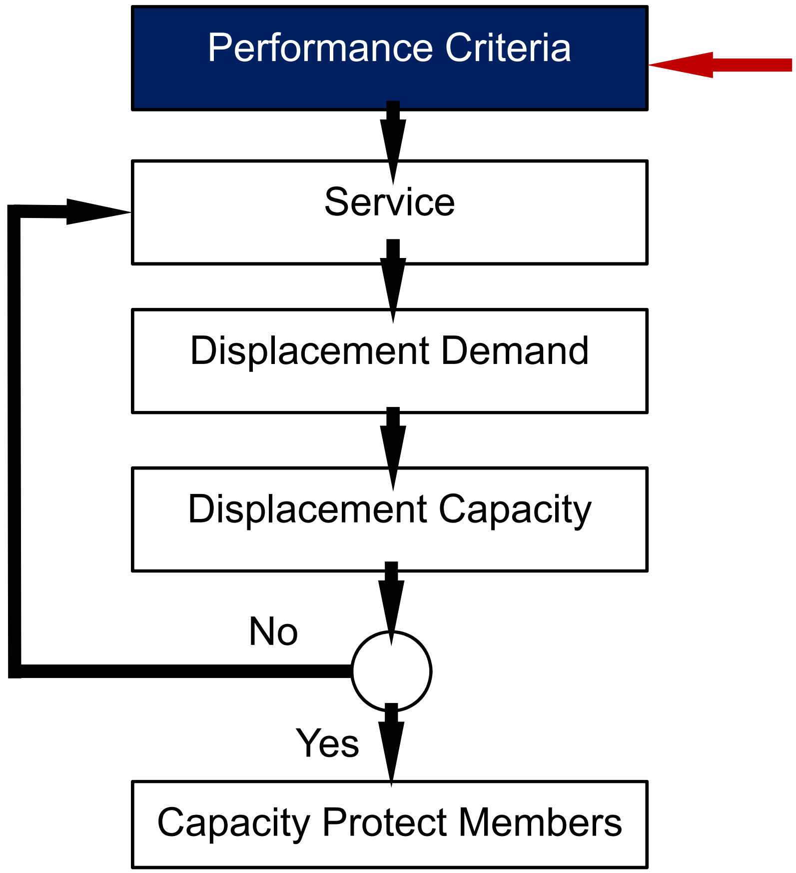
Life Safety or optional "Operational" level.

Analysis under dead, live and time dependent loads

Multi-mode spectral analysis.

Nonlinear pushover analysis.

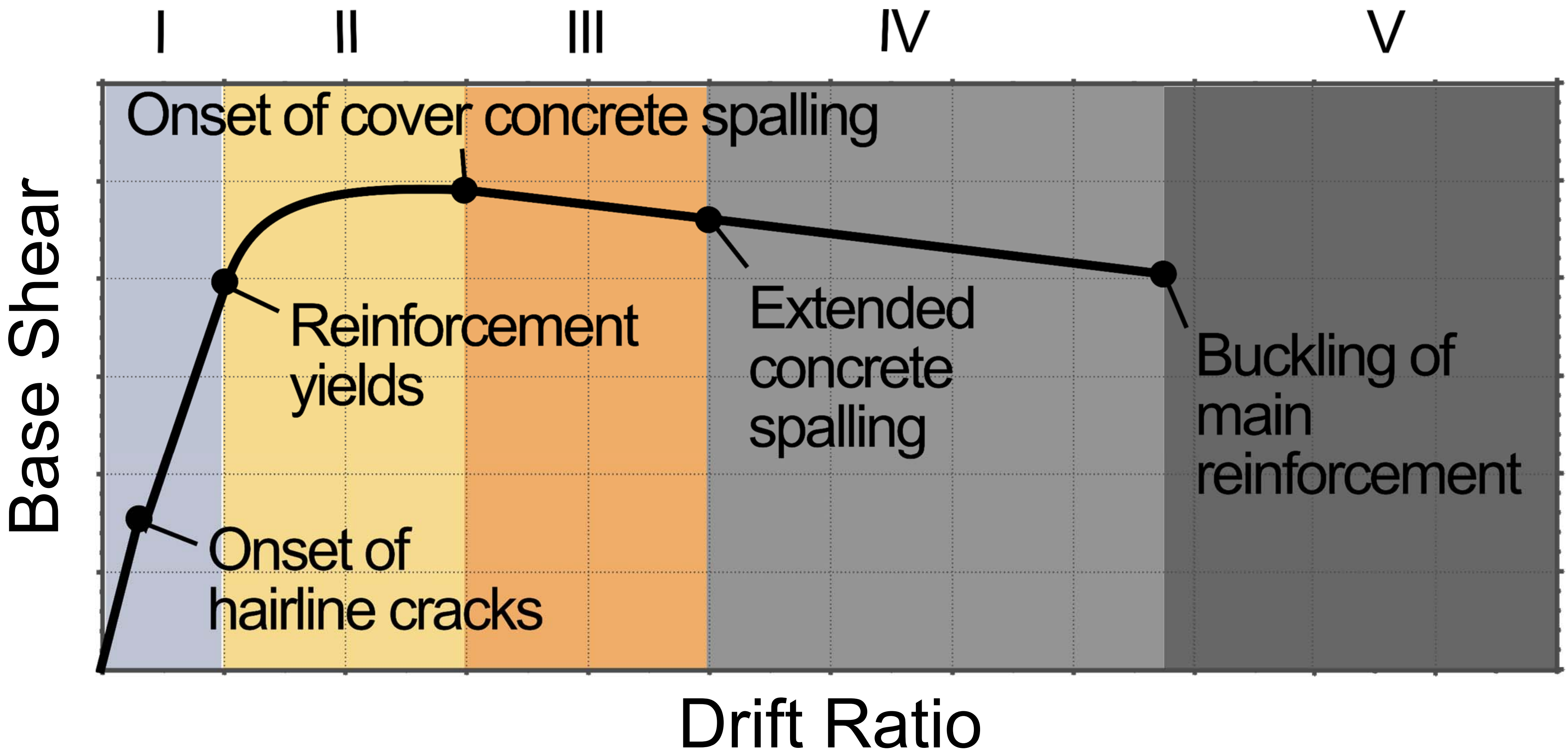
Design Process



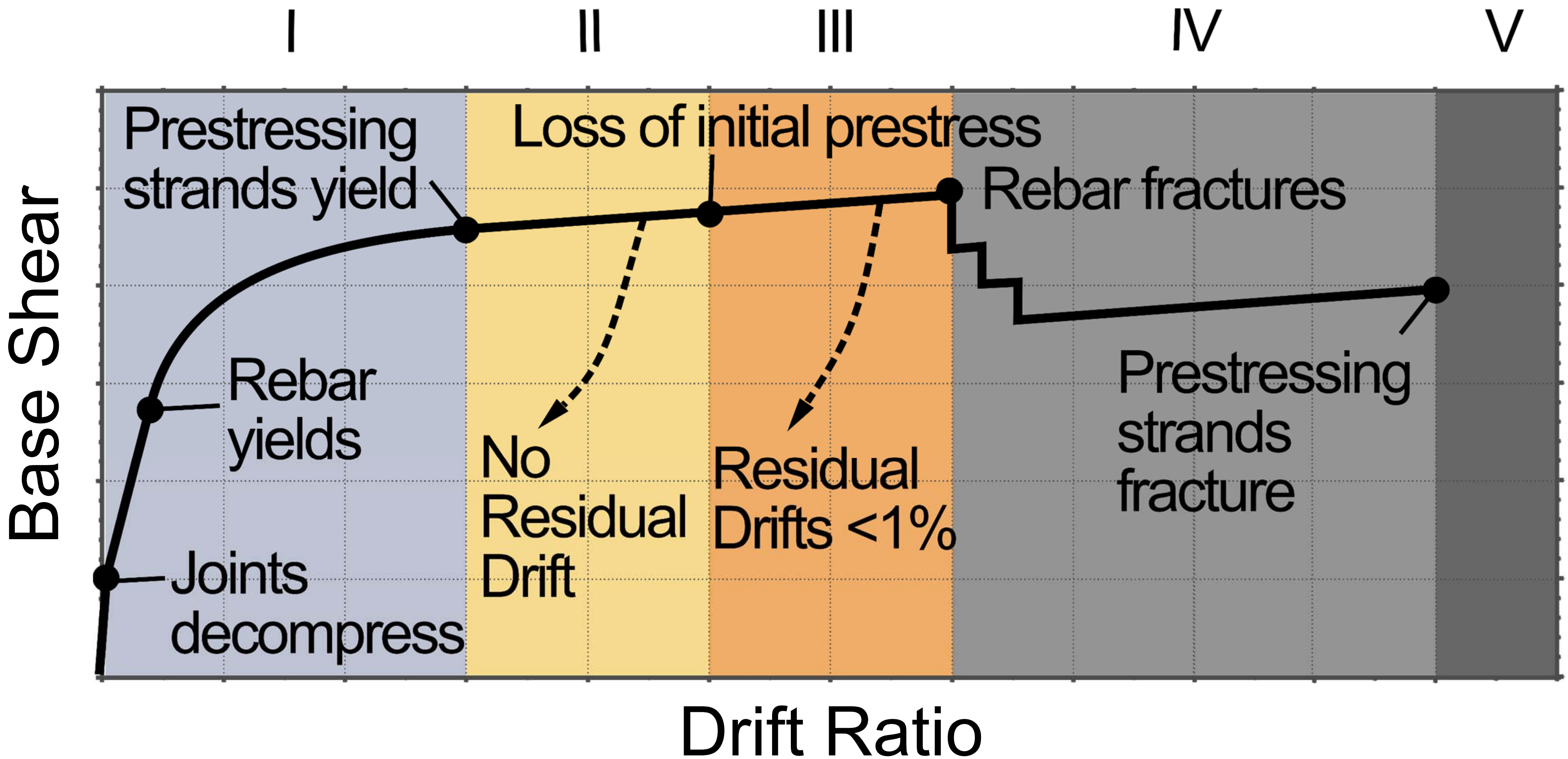
Performance Levels

- **I. Fully Operational**
- **II. Operational**
- **III. Limited Damage**
- **IV. Life Safety**
- **V. Near Collapse**

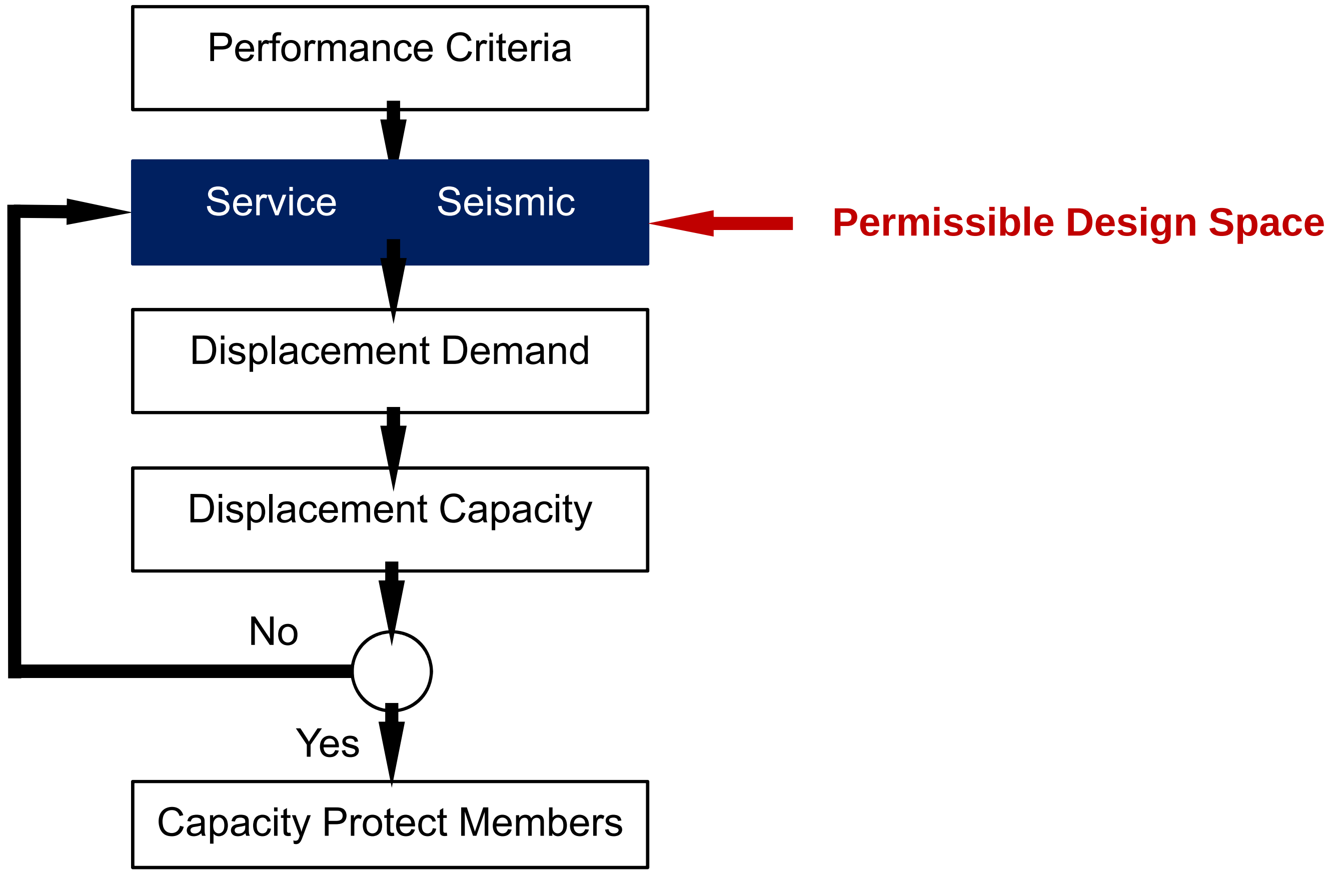
Performance Levels – Conventional



Performance Levels – Pretensioned



Design Process



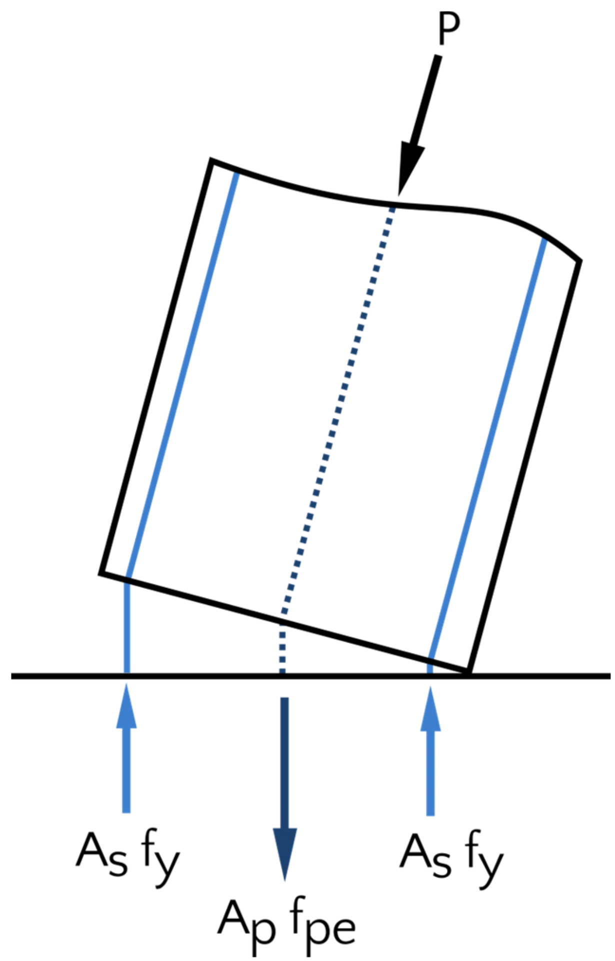
Design Constraints

- **Maximum Longitudinal Reinforcement**
  $A_l \leq 0.04\ A_g$ [AASHTO Article 8.8.1]
- **Minimum Longitudinal Reinforcement**
  $A_l \geq 0.01\ A_g$ [SDC D, AASHTO 8.8.21]
- **Minimum Re-centering Ratio**
- **Maximum Re-centering Ratio**

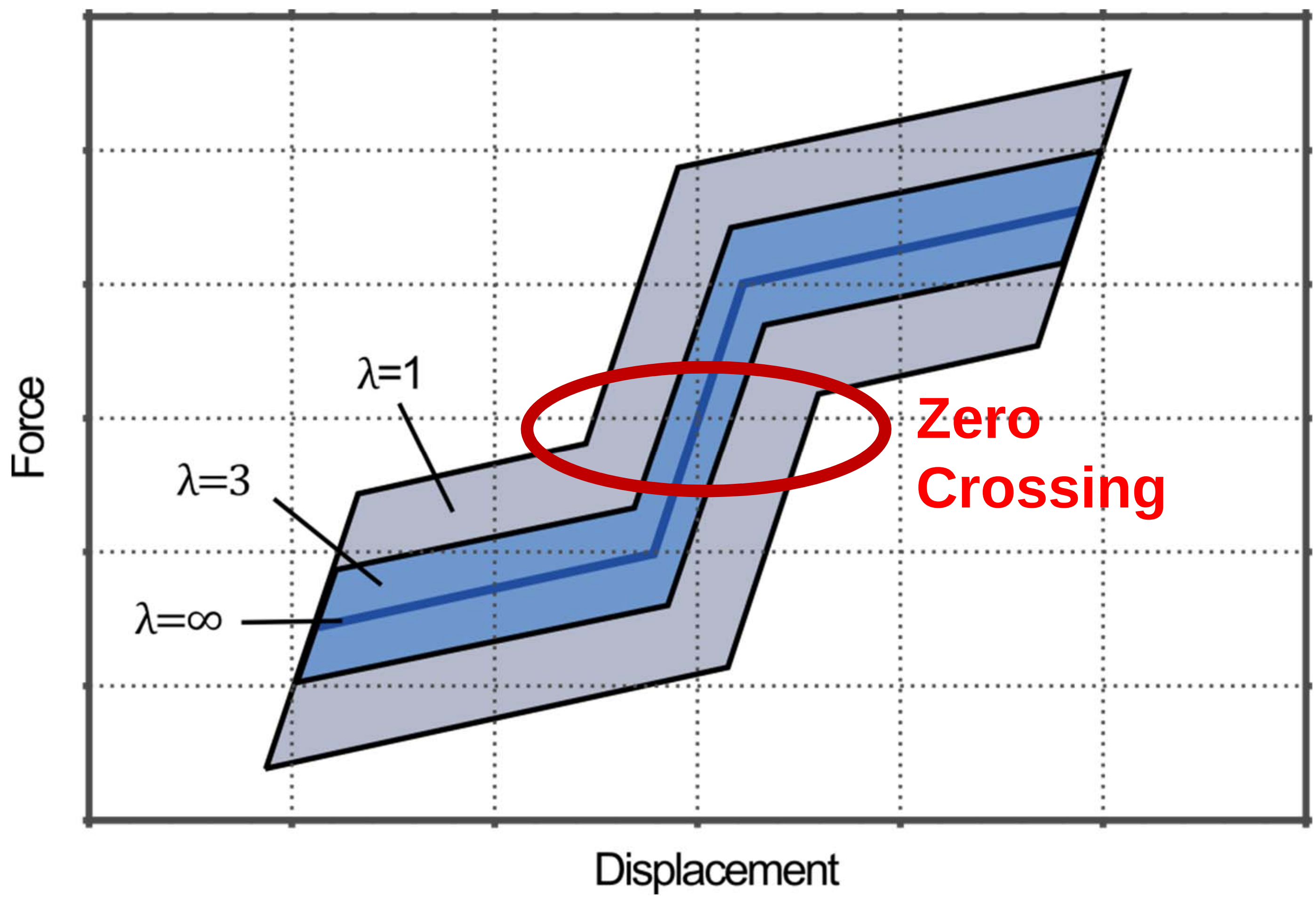
Re-centering Ratio

Determines restoring moments

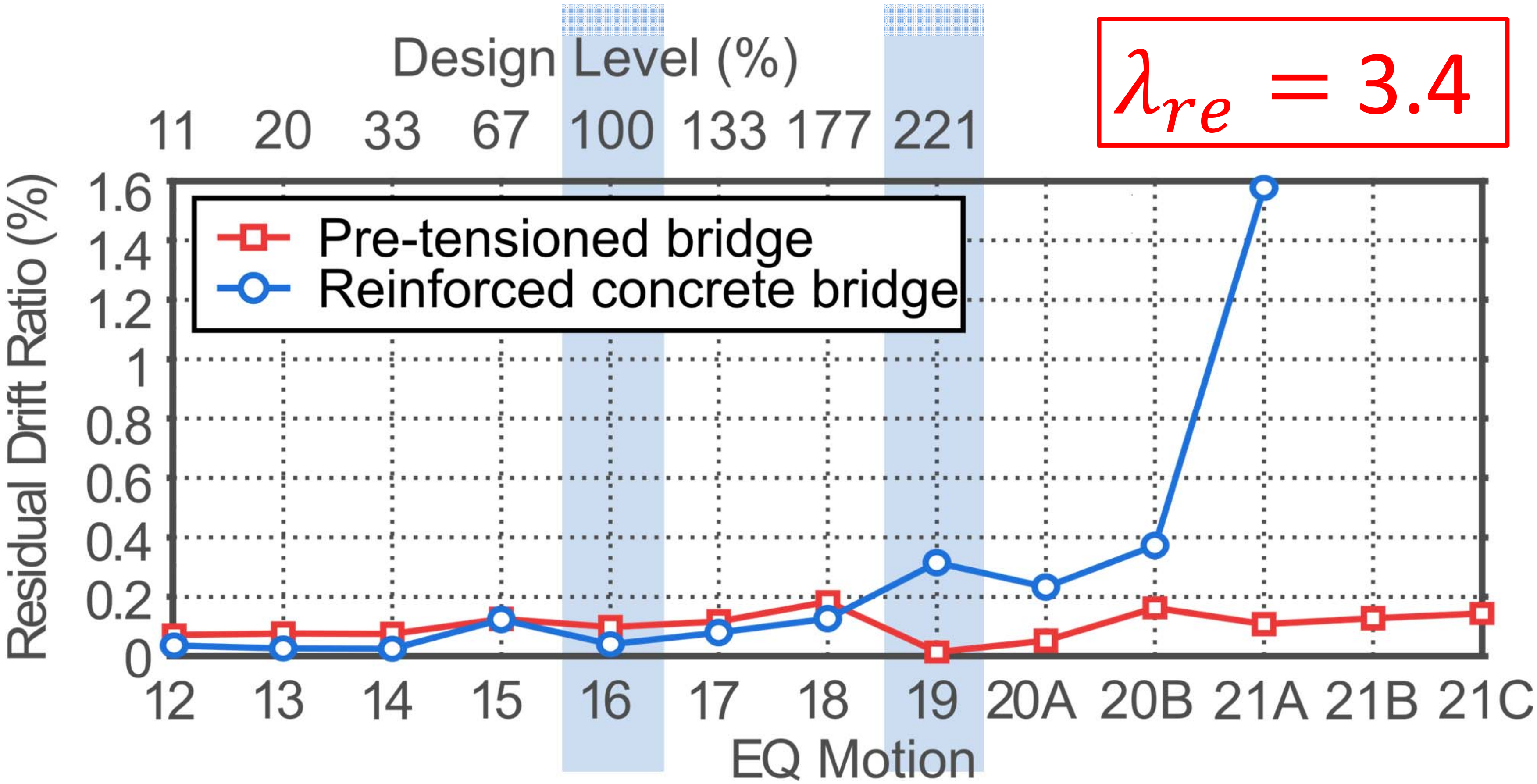
$$\lambda_{re} = \frac{A_p f_{pe} + P}{A_s f_y}$$



Effect of Re-centering Ratio



Residual Displacements

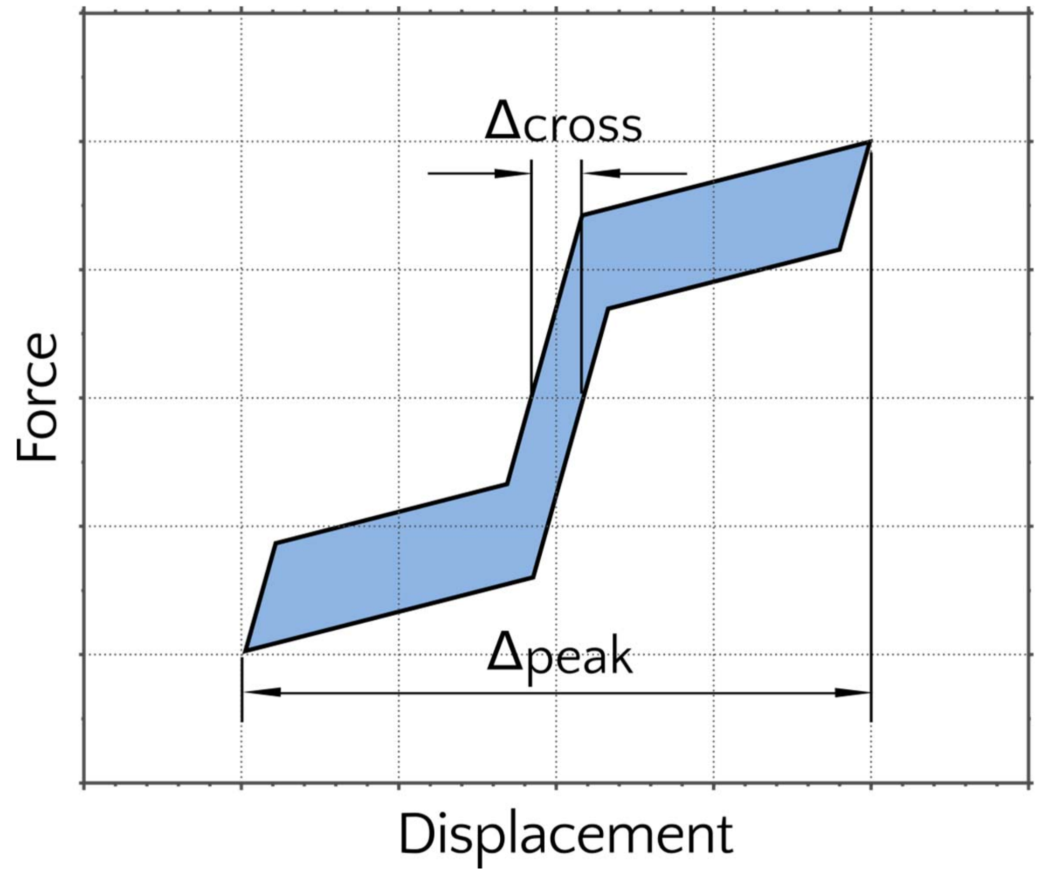


$\lambda_{re} = 3.4$

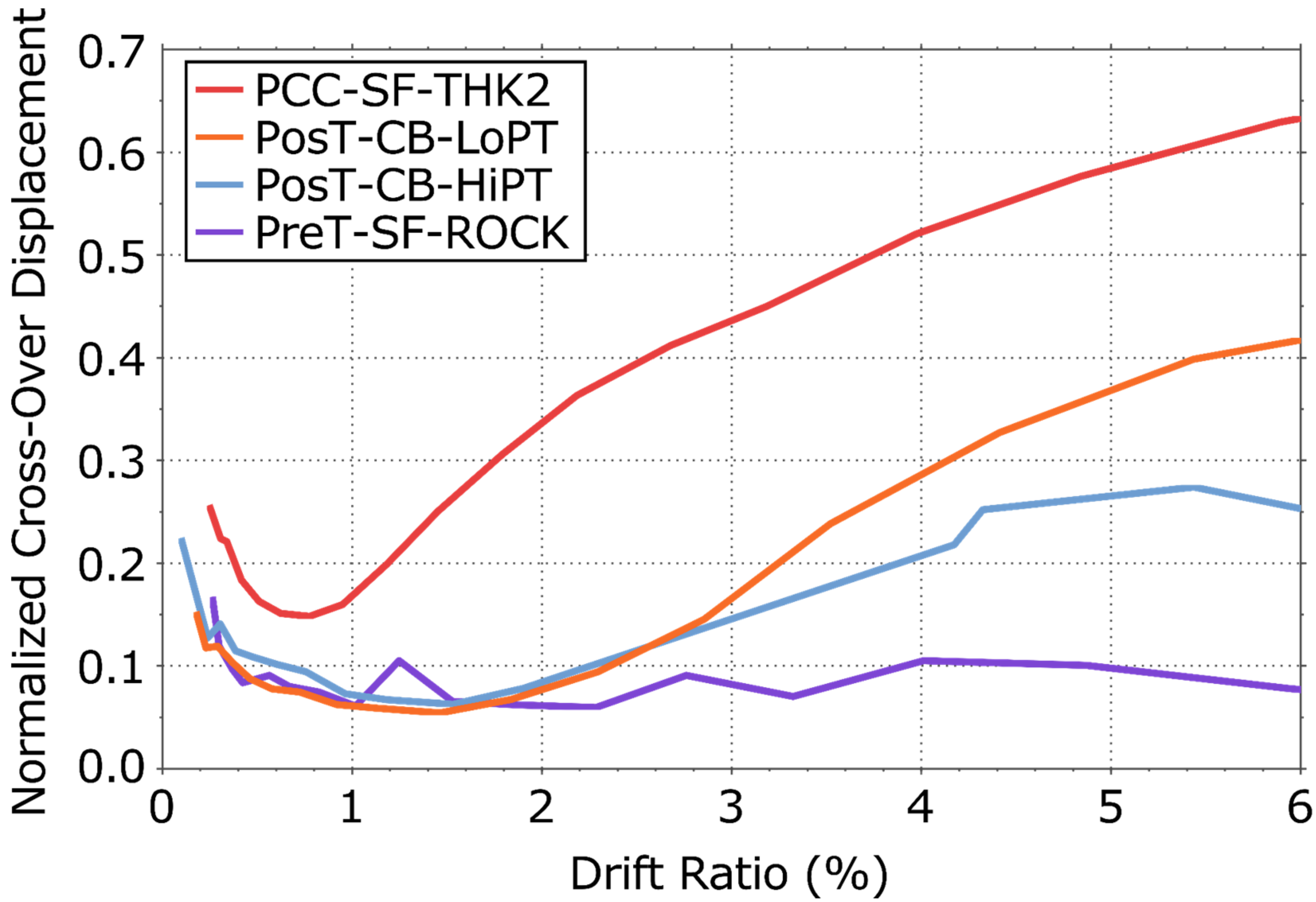
Normalized Cross-Over Displacement

Measure of re-centering performance

$$\text{NCOD} = \frac{\Delta_{cross}}{\Delta_{peak}}$$



Residual Displacements



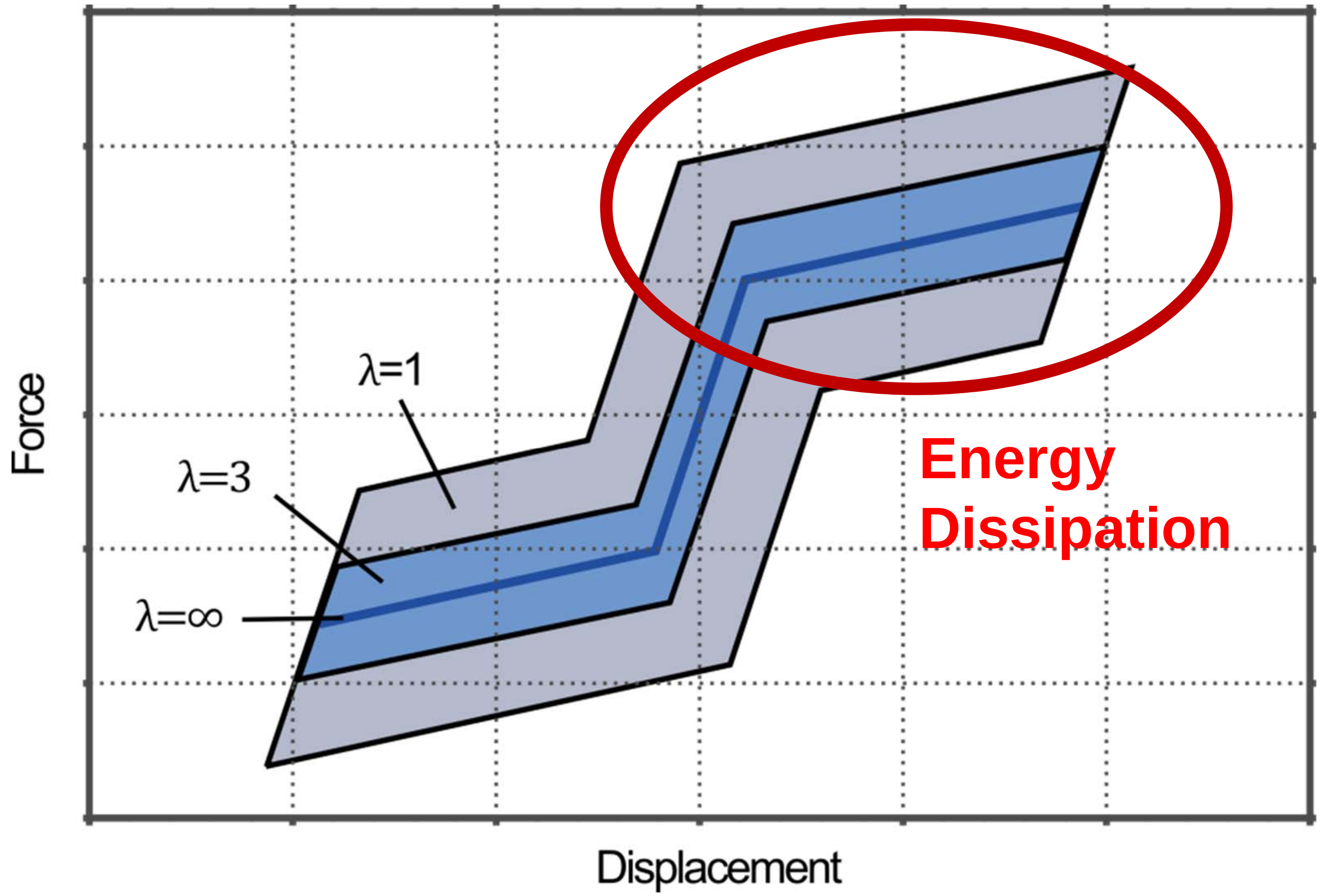
$\lambda_{re} = 0.8$

$\lambda_{re} = 1.2$

$\lambda_{re} = 1.6$

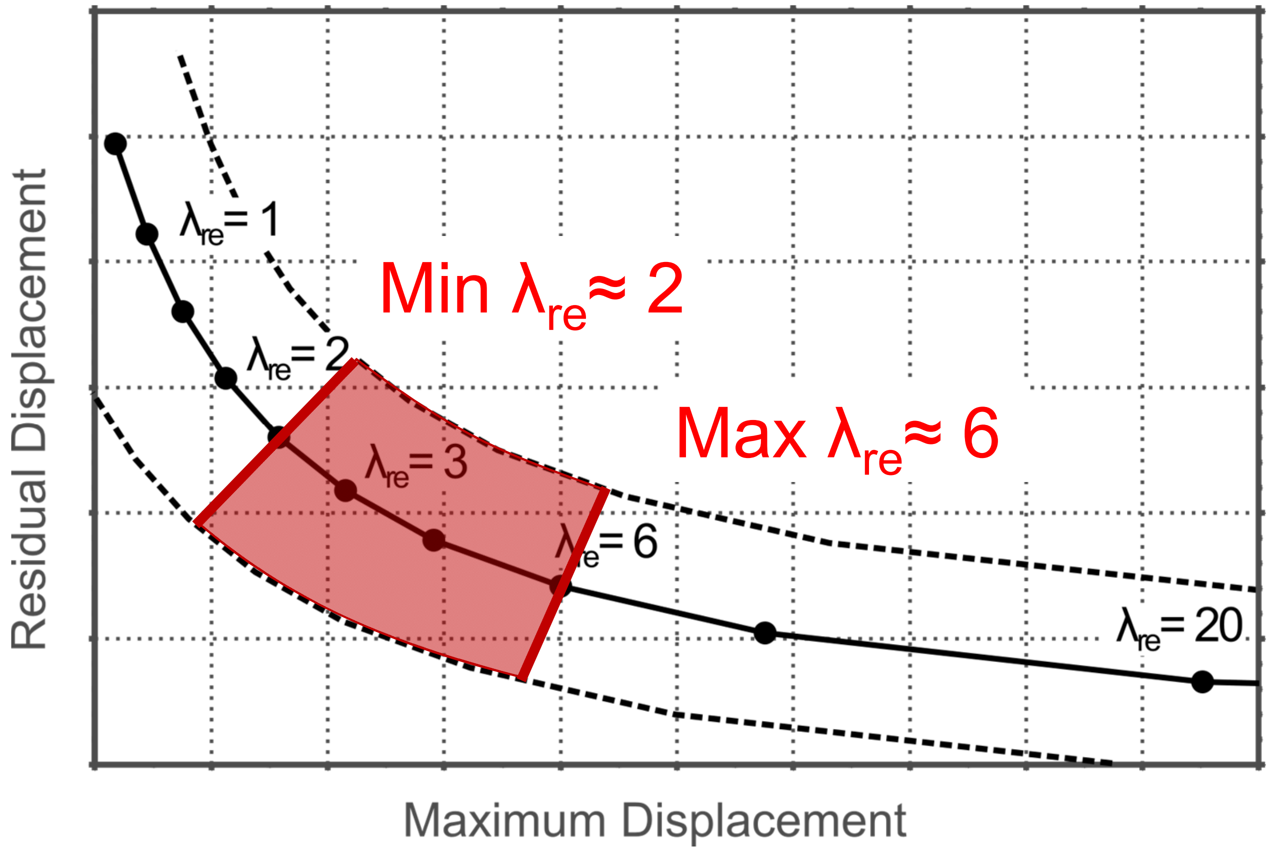
$\lambda_{re} = 3.4$

Effect of Re-centering Ratio

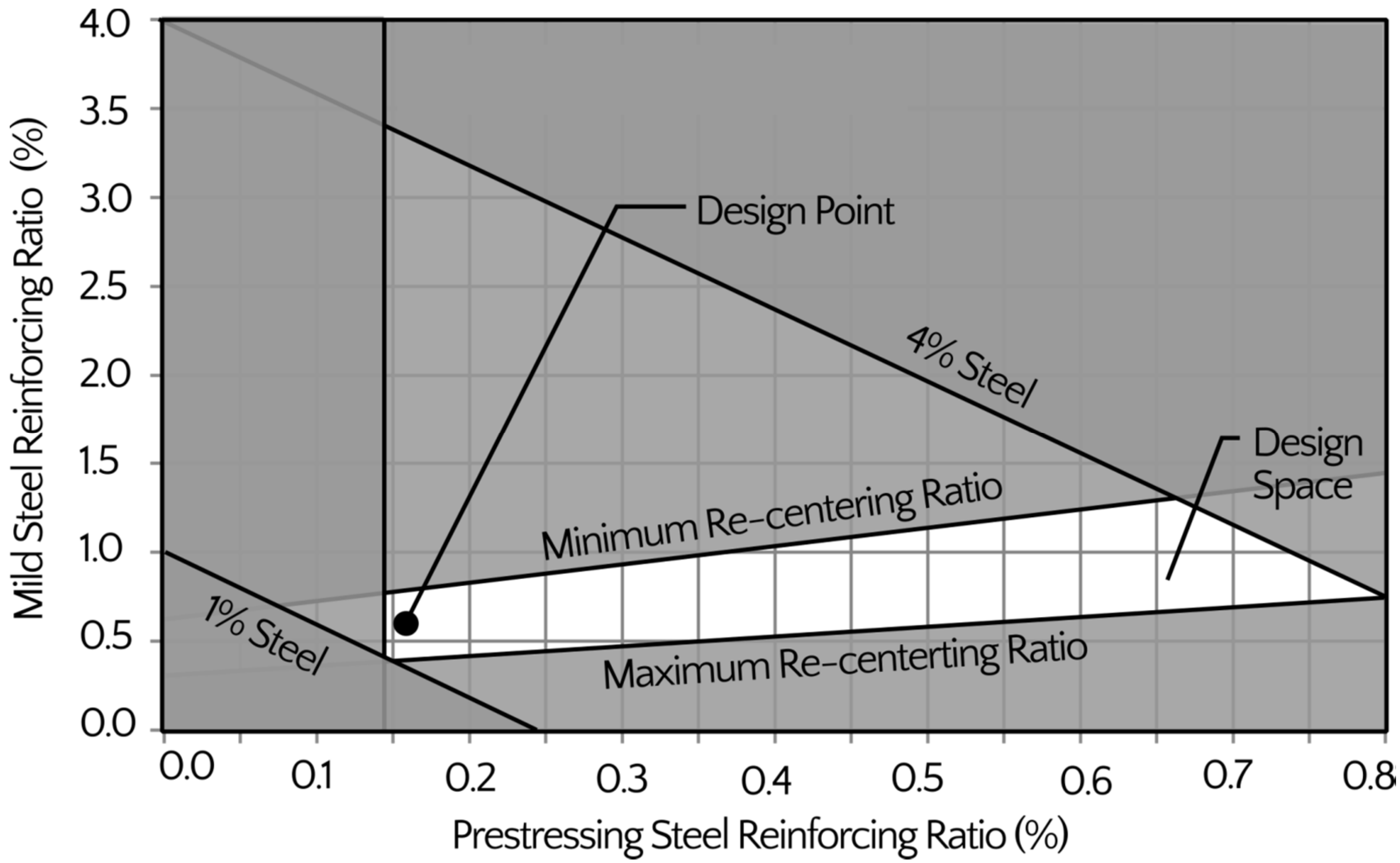


Optimal Re-centering Ratio

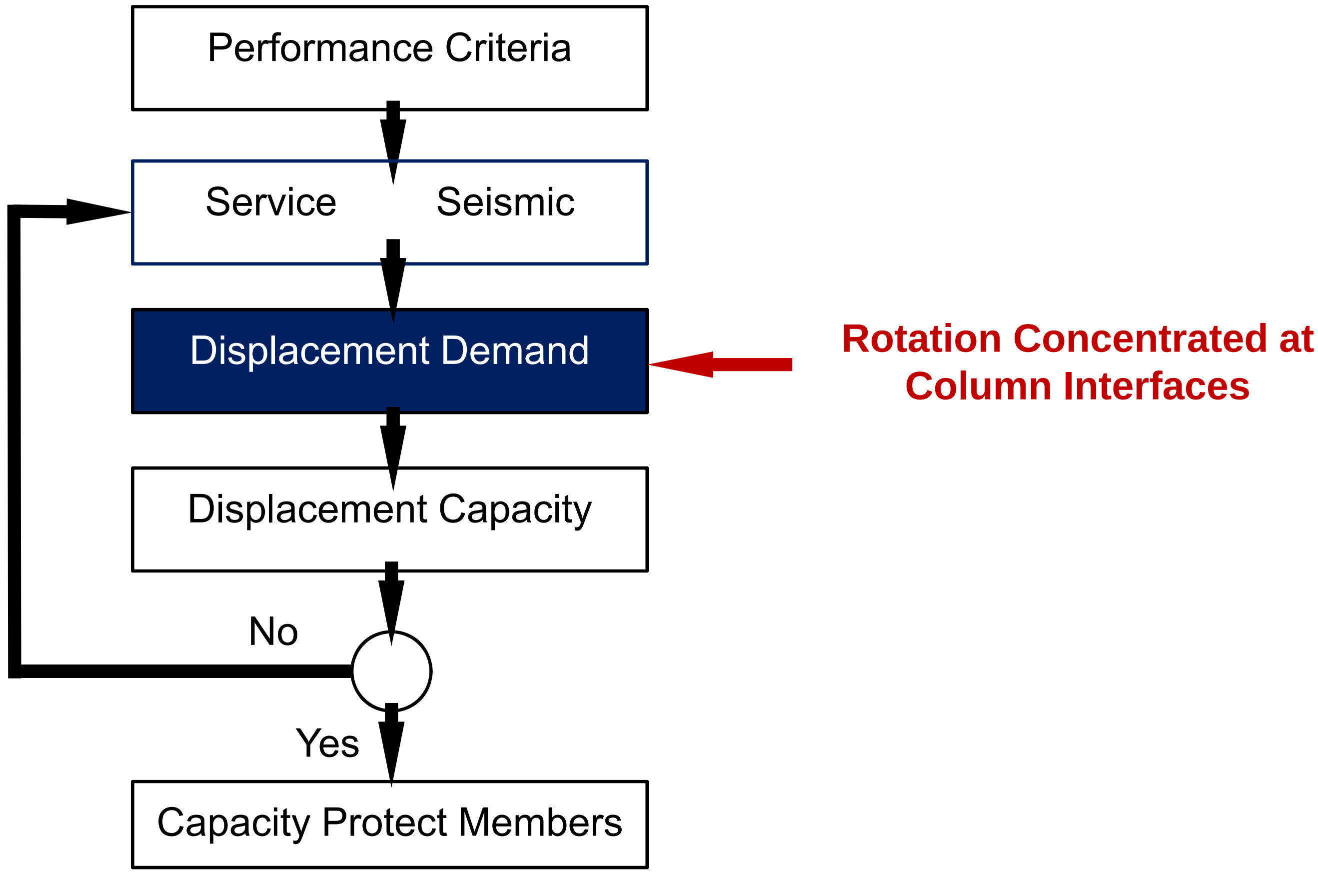
Balance re-centering and energy dissipation .



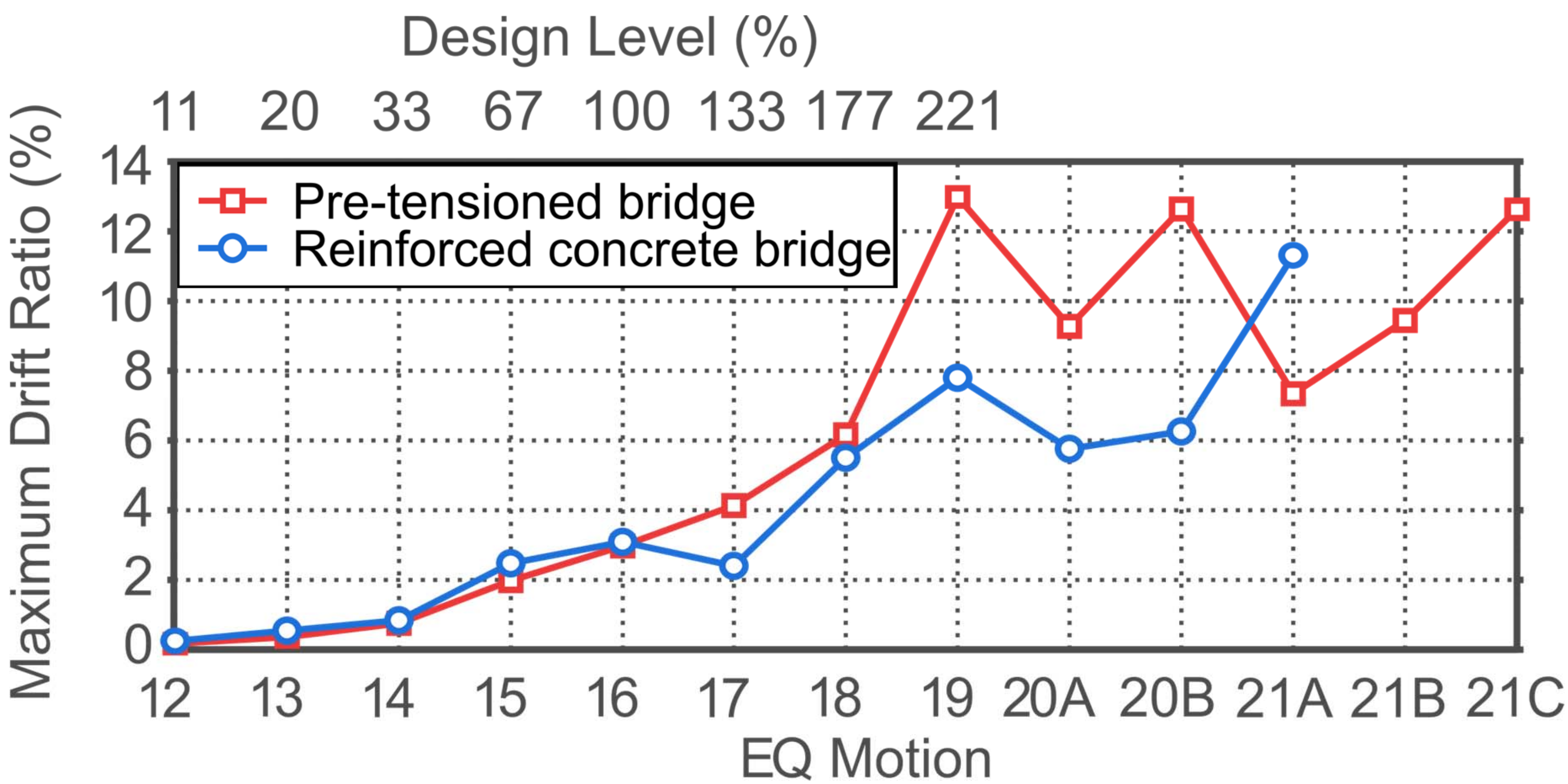
Design Space



Design Process

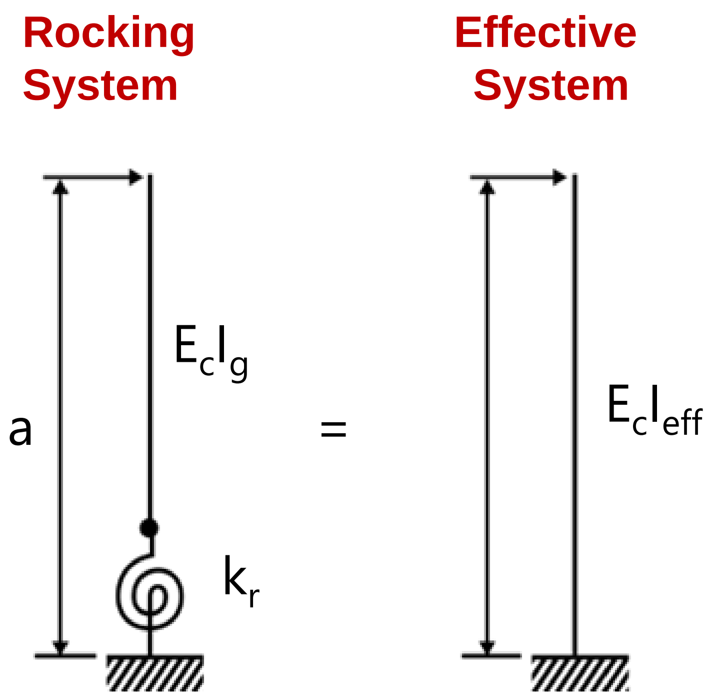


Displacement Demands



Column Effective Stiffness

Account for rotation at rocking interface.



$$\frac{I_{eff}}{I_g} = \frac{1}{1 + \left(3\,E_c\,I_g\right)/\left(a\,k_r\right)}$$

k_r from moment-rotation analysis at interface, or....

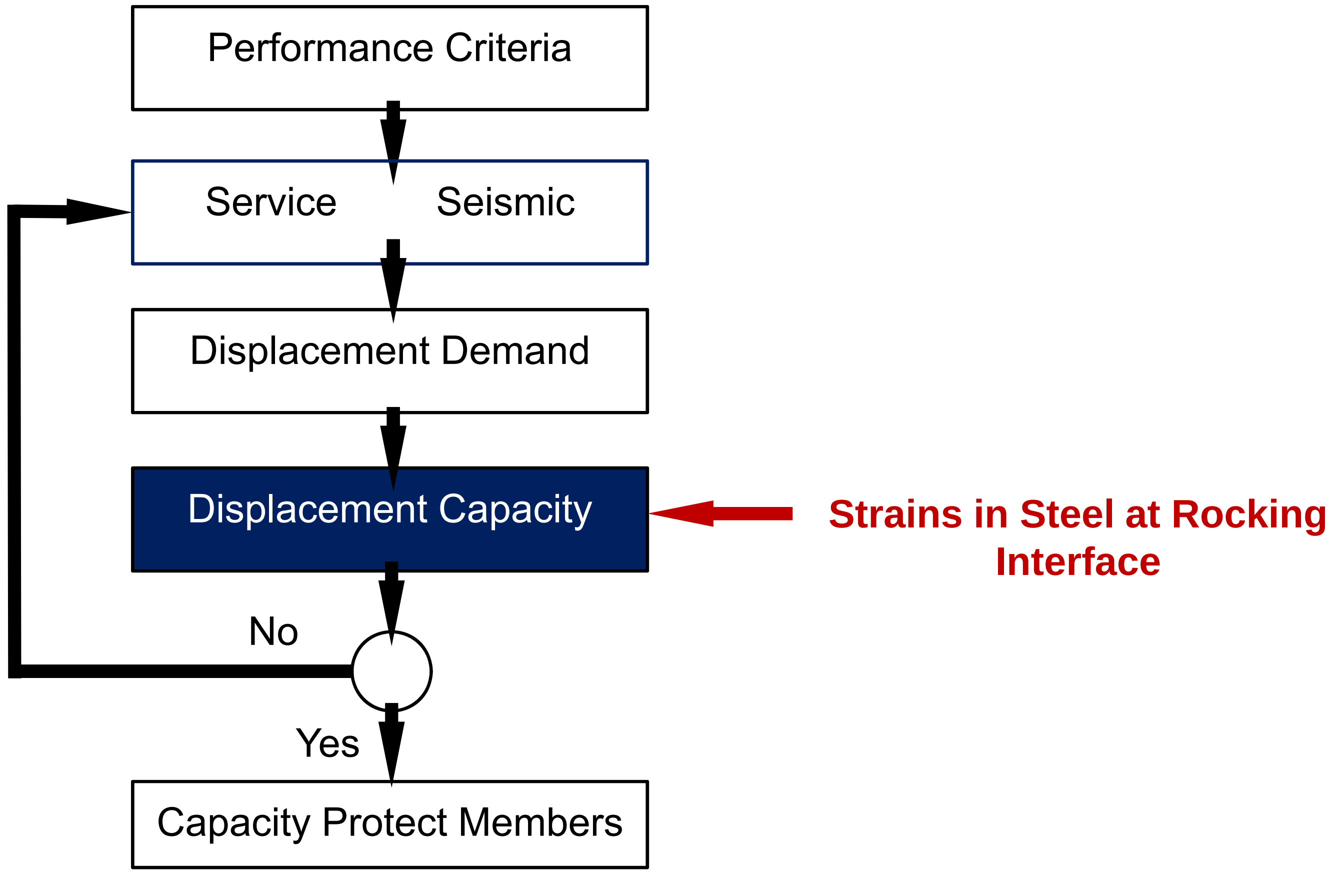
$d_{eff} = D\,(0.5 - 0.15)$

$M_y = d_{eff} * (A_s\,f_y + A_p\,f_{pi} + P)$

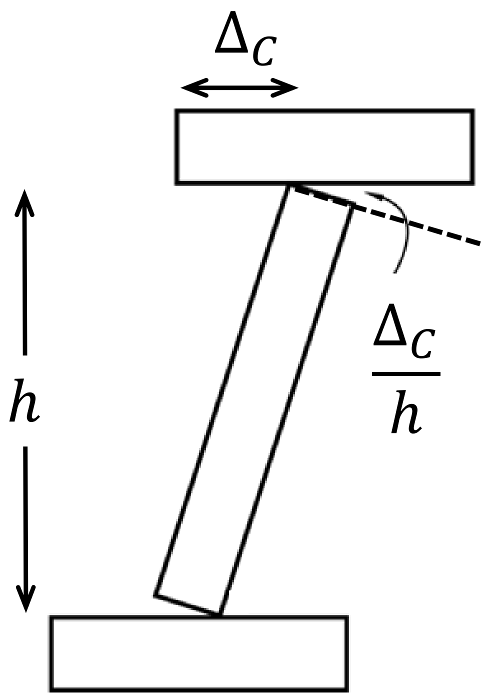
$\theta_y = \varepsilon_y * L_{unb\_eff} / d$

$k_r = M_y / (2 * \theta_y)$

Design Process

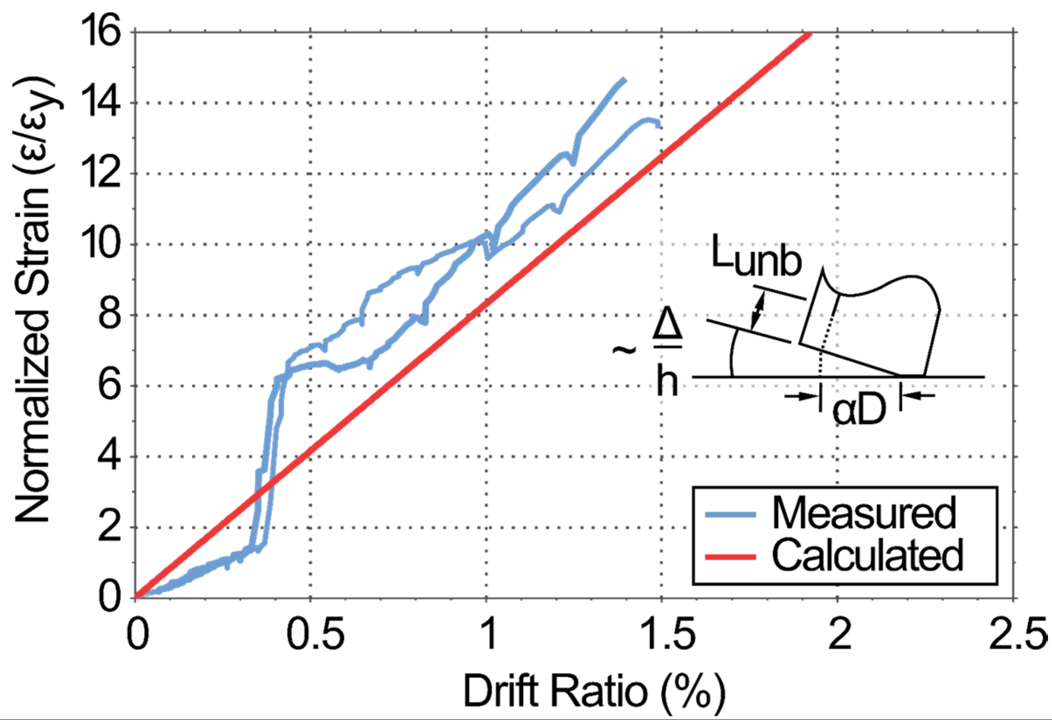


Mild Reinforcement Strains

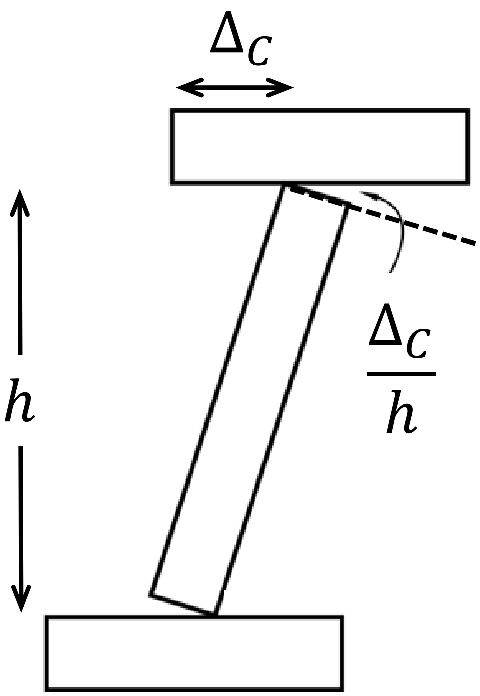


Rebar Fracture: $$\left(\frac{\Delta_C}{h}\right) = \left(\frac{\varepsilon_{su}^{R}\, L_{unb,eff}}{d - 0.15D}\right)$$

$$where\ \ L_{unb,eff} \approx L_{unb} + 6\, d_b$$



Change in Prestressing Steel Strains

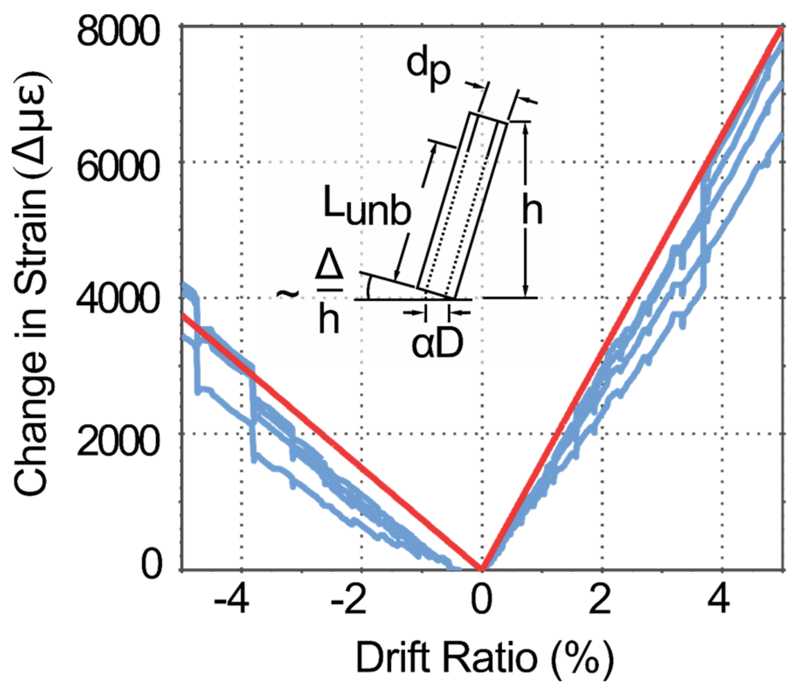


Strand Fracture:

$$\left(\frac{\Delta_C}{h}\right) = \left(\frac{\varepsilon^R_{ps,u}\, L_{unb,eff}}{0.5D - 0.15D}\right)$$

$$where\ L_{unb,eff} \approx H + (f_{ps,u} - f_{se})\left(\frac{A_b/\pi d_b}{4.55\sqrt{f'_c}}\right)$$

(for low-grit epoxy coated strands)



Conclusions

1. Pre-Tensioned, Rocking Bent System:
   - Faster construction
   - Less damage
   - Lower residual displacements
2. Reentering and energy dissipation depends on recentering ratio,λ_{re}
3. Design procedure is similar (easier?) than that for conventional bridges

Thank You


http://blogs.r.ftdata.co.uk/photo-diary/files/2013/07/RUSH-HOUR.jpg

Thank You

Pre-Tensioned, Rocking Bent System

Overview

- Accelerate construction
- Reduce residual displacements
- Eliminate damage to column concrete

Trends

- Specimen assembled in 25% of time required for similar RC.
- Residual displacements and concrete damage nearly eliminated.

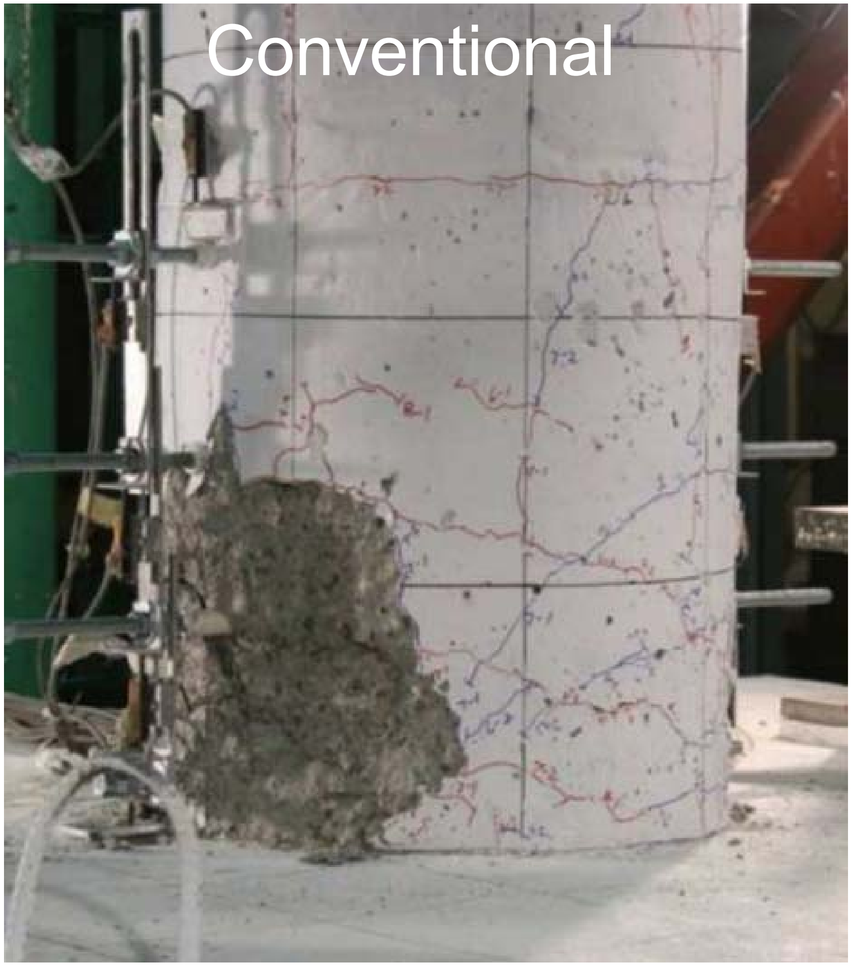
Challenges

- New technology.
- Special measures needed to identify bar fracture.

Practical Uses

- Ready for implementation for typical bridges.
- Design methodology available.

Subassembly Tests (4.3% Drift Ratio)



Equivalent Reinforcing Ratio.

- Accounts for the higher strength of the strands.

Equivalent Reinforcing Ratio.

$$\rho_{equiv} = \rho_s + \rho_p\left(f_{py}/f_{sy}\right)$$

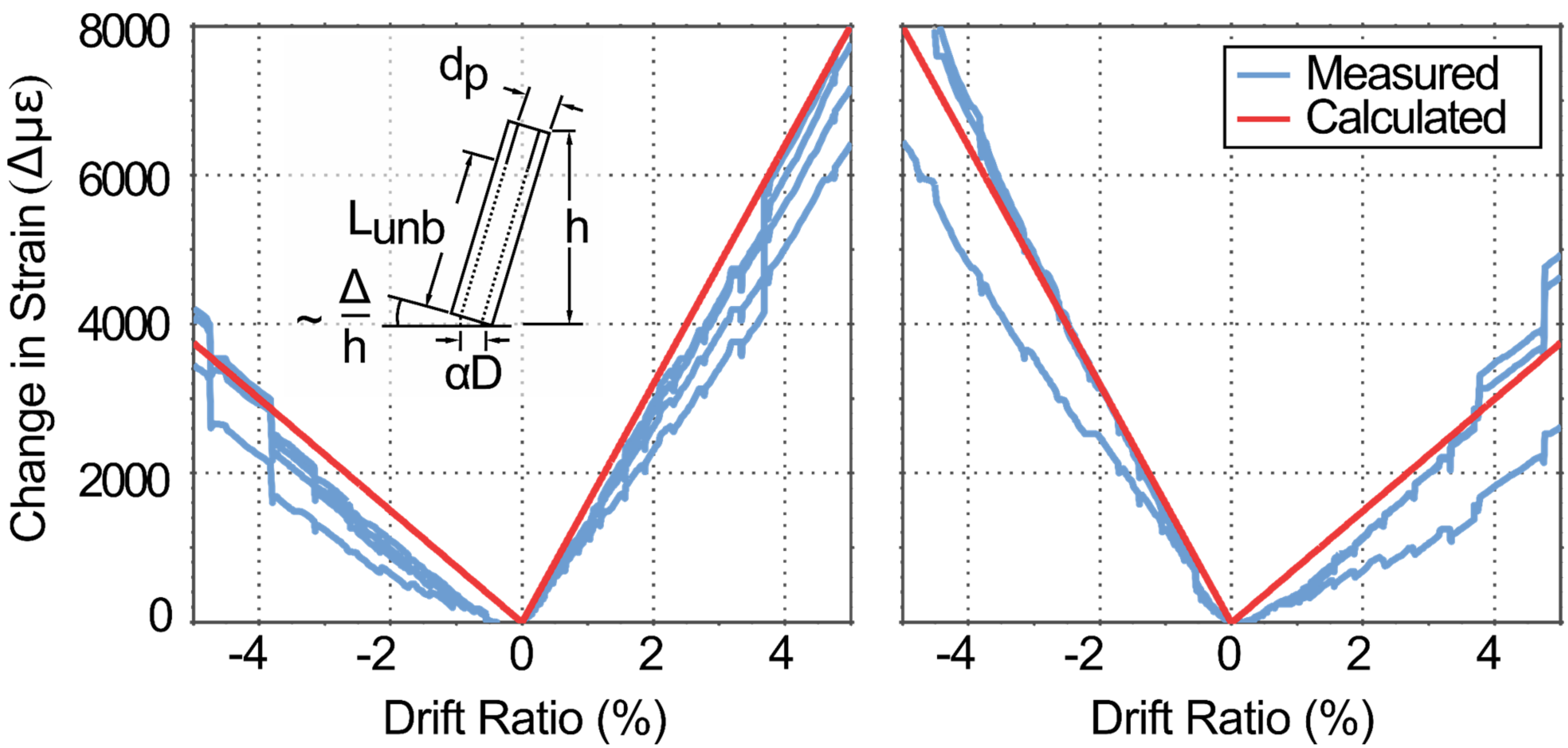
Deformed Bar Reinforcing Ratio.

$$\rho_s = A_s/A_g$$

Prestressing Strand Reinforcing Ratio.

$$\rho_p = A_p/A_g$$

Change in Strand Strain vs. Drift



Conclusions

System Satisfies Objectives

Precast columns and cap beams save two casting and curing cycles on-site.

Partially unbonded strands re-center the bridge after the earthquake is over.

Confined rocking detail prevents spalling and inhibits bar buckling.

Design

Re-centering ratio, λ_{re}, determines cross-over displacements (residual displacement)

Pre-tensioned, rocking systems can achieve higher performance levels than conventional systems

Accelerated Construction

Precast columns and cap beams save two casting and curing cycles on-site.

Pre-tensioned shake table specimen assembled in 25% of time required for conventional cast-in-place.

Eliminate Residual Displacements

Partially unbonded strands re-center the bridge after the earthquake is over.

Residual drift ratios less than 1% in shake table tests.

Reduce Column Damage

Rocking detail prevents spalling and inhibits bar buckling.

Because column concrete is not damaged, special measures are needed to identify bar fracture.

Design

Minimal modifications to current procedure

Re-centering ratio, λ_{re}, determines re-centering performance.

Pre-tensioned rocking systems can achieve higher performance levels than conventional systems.