Self-Centering Seismic-Resistant Steel Frame Systems: Overview of Past and Current Research

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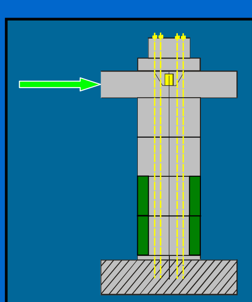
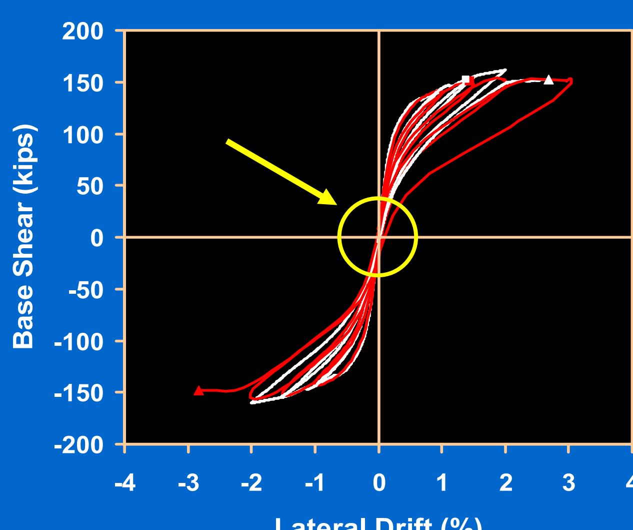
Self-Centering (SC) Seismic-Resistant Structural Systems

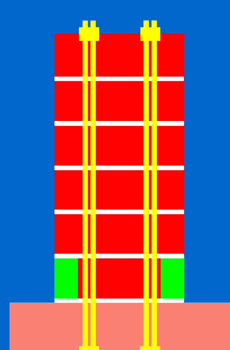




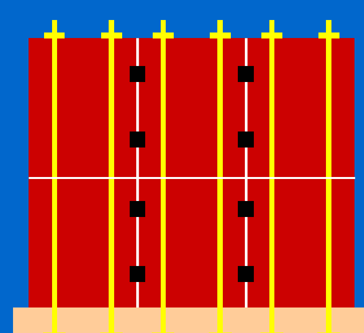
Previously Studied SC Seismic-Resistant Structural Systems

- Unbonded post-tensioned precast walls:
  - With and without energy dissipation elements
- Unbonded post-tensioned precast moment-resisting frames:
  - Without energy dissipation elements
- Steel moment resisting frames with post-tensioned connections:
  - With energy dissipation elements

SC Seismic-Resistant Structural Systems

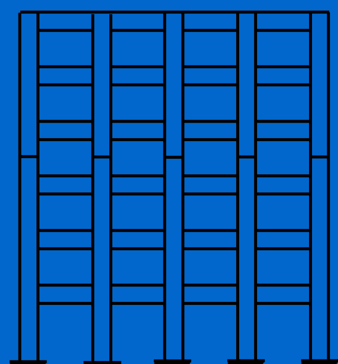


Unbonded post-tensioned (PT) precast walls

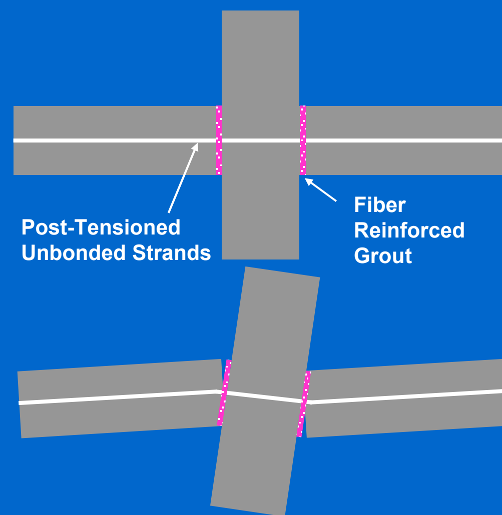


Unbonded PT precast walls with ductile vertical joint connectors

SC Seismic-Resistant Structural Systems

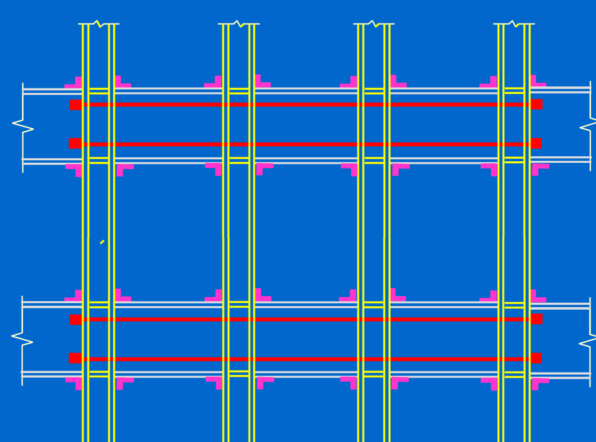


Unbonded post-tensioned precast frames



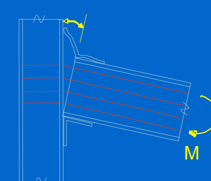
SC Earthquake-Resistant Structural Systems

- Steel moment-resisting frames (MRFs) with post-tensioned connections:
  - with top and bottom seat angles
  - with friction devices



SC Seismic-Resistant Structural System Concepts

- Structural systems are post-tensioned to pre-compress joints between discrete structural members
- Gap opening at joints at selected seismic load levels provides softening of lateral force-drift behavior without damage to members
- PT forces close joints and permanent lateral drift is avoided



SC Seismic-Resistant Structural System Features

1. Economy, since structural member size and complexity in SC systems are similar to conventional seismic-resistant systems
2. Reduced damage, since SC systems can be designed to resist design basis earthquake without significant damage

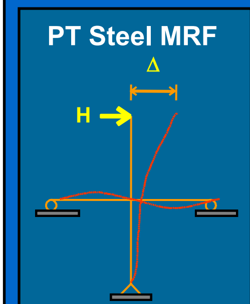
SC Seismic-Resistant Structural System Features

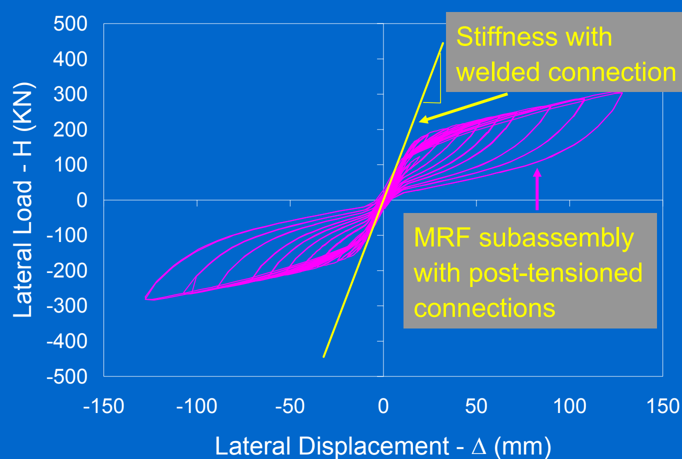
3. Initial lateral stiffness is similar to that of conventional seismic-resistant systems
4. Lateral force-drift behavior softens:
   - to control force demands under seismic load
   - due to gap opening at selected joints
   - without significant inelastic deformation and damage to main structural members, avoiding residual drift

SC Seismic-Resistant Structural System Features

5. Ductility capacity:
   - can be quite large
   - is not fully controlled by material ductility
   - can be enhanced by changes in post-tensioning
6. Energy dissipation:
   - from energy dissipation elements
   - not from damage to main structural members

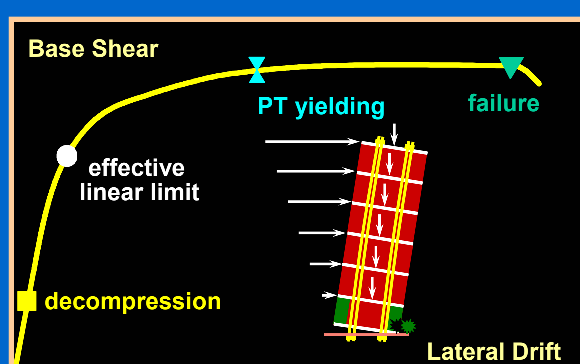
Initial Stiffness Is Similar to Stiffness of Conventional Systems





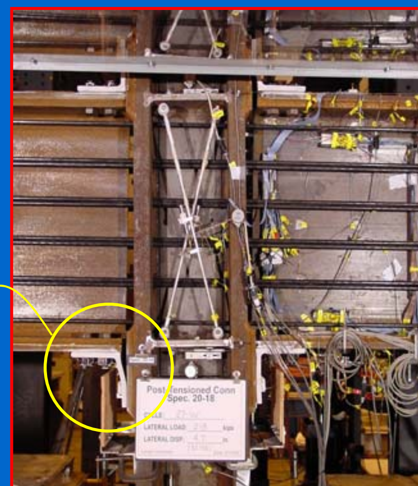
Lateral Force-Drift Behavior Softens to Control Force Demands

- Softening controls acceleration and force demands under seismic loading



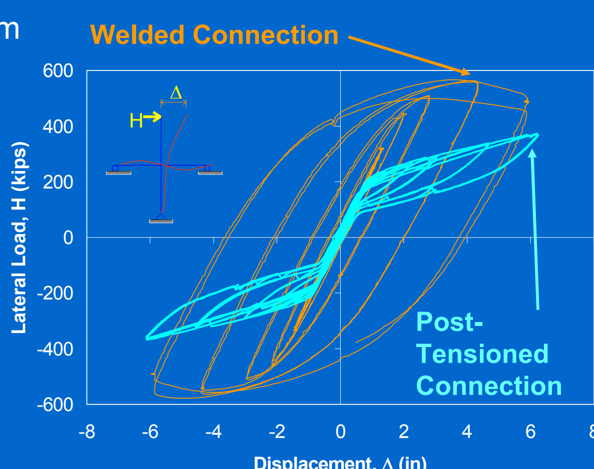
Lateral Force-Drift Behavior Softens Due to Gap Opening

Steel MRF subassembly with post-tensioned connections and angles at 3% drift



Lateral Force-Drift Behavior Softens Without Inelastic Deformation

- Conventional system softens by inelastic deformation which damages main structural members and results in residual drift
- Self-centering system softens by gap opening and reduced contact area at joints



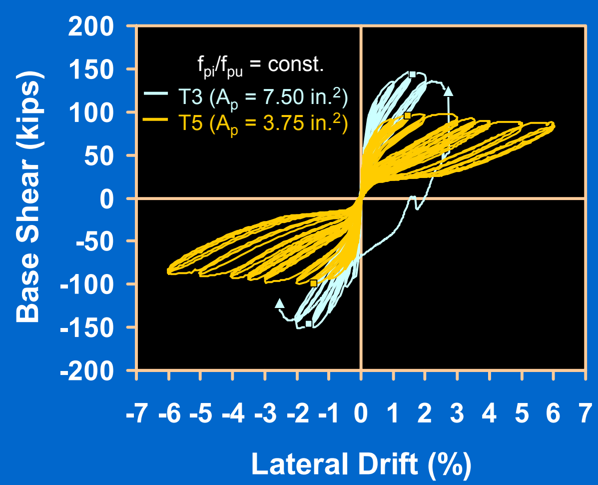
Lateral Force-Drift Behavior Softens Due to Gap Opening

Unbonded post-tensioned precast wall at 3rd cycle to 3% drift

Lateral Force-Drift Behavior Softens Without Inelastic Deformation, Avoiding Residual Drift

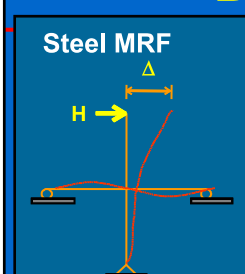
Unbonded post-tensioned precast wall after 3rd cycle to 3% drift

Ductility Capacity

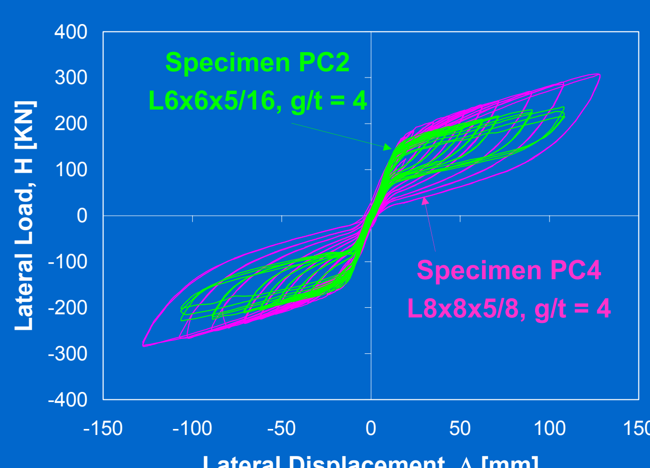


- Can be quite large
- Is not fully controlled by material ductility
- Can be enhanced by changes in post-tensioning

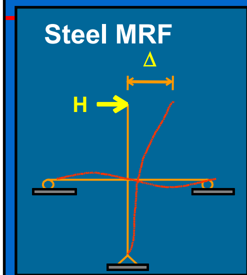
Energy Dissipation from Energy Dissipation Elements



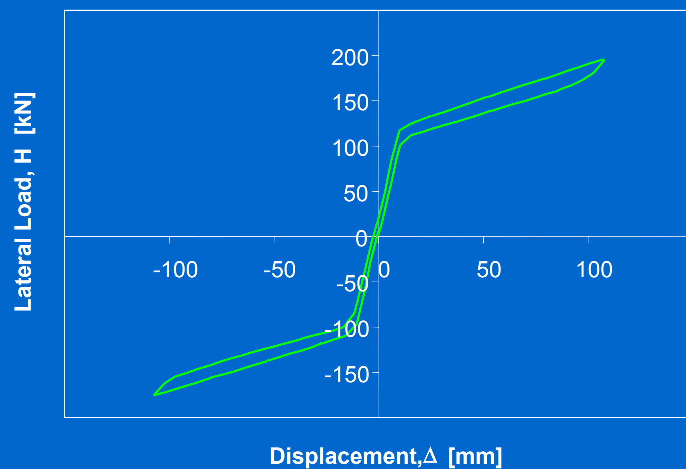
Steel MRF subassemblies with post-tensioned connections with different size angles



Energy Dissipation Not from Damage to Main Structural Members



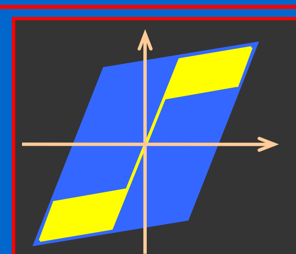
Steel MRF subassemblies with post-tensioned connections with no angles

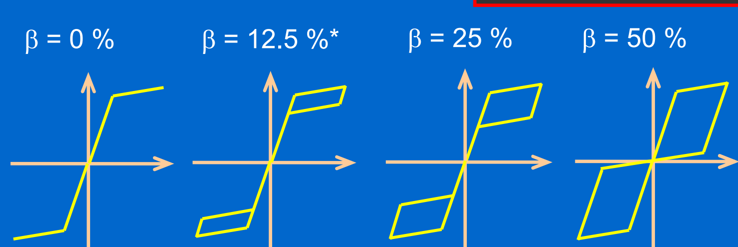


Relative Energy Dissipation of SC Systems

β: Relative energy dissipation capacity

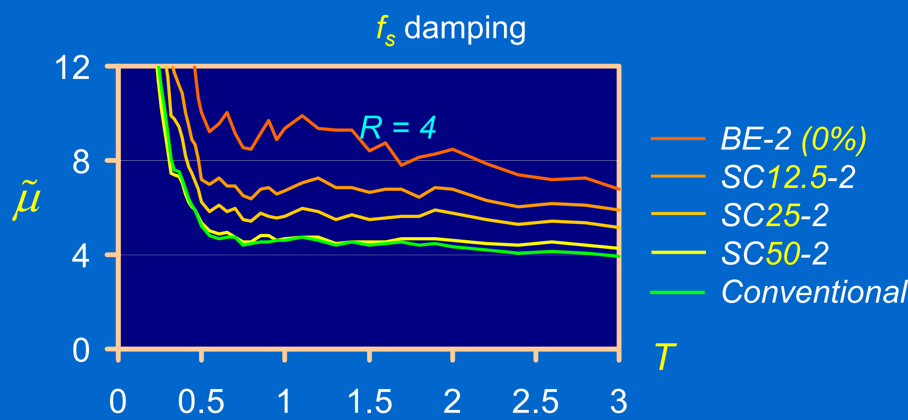
$$\beta = \frac{\text{Area of yellow}}{\text{Area of blue}} x100(\%)$$





* Minimum per ACI T1.1-01.

Effect of Energy Dissipation on Ductility Demand



Energy Dissipation

- SC systems should have energy dissipation elements
- These elements may be damaged and replaced
- Behavior of these elements will control system energy dissipation, with no significant energy dissipation from main structural members

Summary of SC Seismic-Resistant Structural System Features

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Summary of Past Research

- Studies of different SC seismic-resistant structural systems have been conducted
- Studies have identified attractive features summarized earlier
- Seismic performance can exceed that of conventional systems (reduced residual drift, reduced damage)

NEESR SC Steel Frame Systems Project Goals

- Overall: self-centering steel systems that are constructible, economical, and structurally damage-free under design earthquake
- Specific:
  - fundamental knowledge of seismic behavior of SC-MRF systems and SC-CBF systems
  - integrated design, analysis, and experimental research using NEES facilities
  - performance-based, reliability-based seismic design procedures

Research Needs for SC Moment Resisting Frames (SC-MRFs)

- Interaction between SC-MRFs and floor diaphragms
- Improved energy dissipation elements for SC-MRF connections
- SC column base connections for SC-MRFs
- Parametric studies of SC-MRFs for various buildings
- Design procedures for SC-MRFs with clear performance objectives and reliability concepts
- Large-scale tests on SC-MRF systems, including floor diaphragms, with realistic seismic input

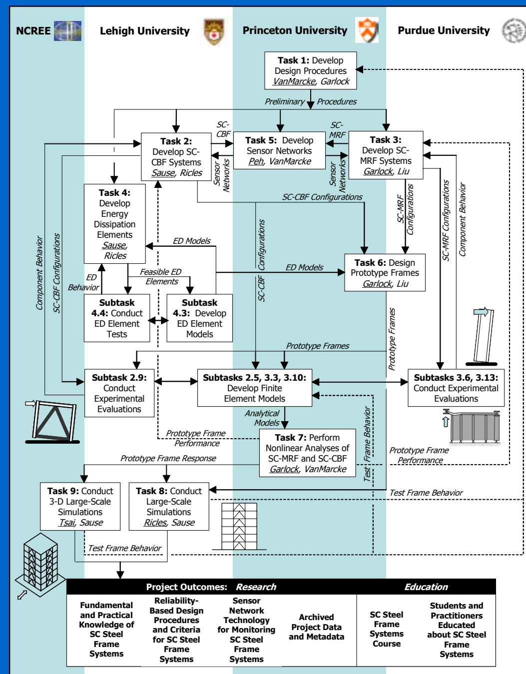
Research Needs for SC Concentrically Braced Frames (SC-CBFs)

- PT systems and connection concepts for SC-CBFs
- Analytical models for SC-CBFs
- Initial laboratory studies of SC-CBFs
- Energy dissipation elements for SC-CBFs
- SC column base connections for SC-MRFs
- Design procedures for SC-CBFs with clear performance objectives and reliability concepts
- Large-scale tests on SC-CBF systems, including floor diaphragms, with realistic seismic input

Research Tasks

1. Develop reliability-based seismic design and assessment procedures
2. Develop SC-CBF systems
3. Further develop SC-MRF systems
4. Develop energy dissipation elements for SC-MRFs and SC-CBFs
5. Develop sensor networks for damage monitoring and integrity assessment
6. Design prototype buildings
7. Perform nonlinear analyses of prototype buildings
8. Conduct large-scale laboratory tests of SC-MRFs and SC-CBFs
9. Collaborate on 3-D large-scale laboratory experiments on SC-MRF and SC-CBF systems

Research Tasks



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Thank You

Questions?