The National Academies of
SCIENCES • ENGINEERING • MEDICINE

TRANSPORTATION RESEARCH BOARD

Seismic Design and Accelerated Bridge Construction

Wednesday, July 11, 2018
2:00-4:00 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Discuss the relationship between the use of accelerated bridge construction techniques and general seismic design performance.

Learning Objectives

At the end of this webinar, you will be able to:

- Understand seismic bridge design philosophy used as the basis of bridge design specifications
- Describe the challenges associated with ABC connections in high seismic regions
- Describe the effects that mechanical couplers may have on plastic deformation capacity of bridge columns
- Identify some of the novel materials and techniques available to improve seismic bridge response

TRB Webinar

Seismic Design and Accelerated Bridge Construction (ABC)

Lee Marsh PhD PE
President
BergerABAM

11 July 2018

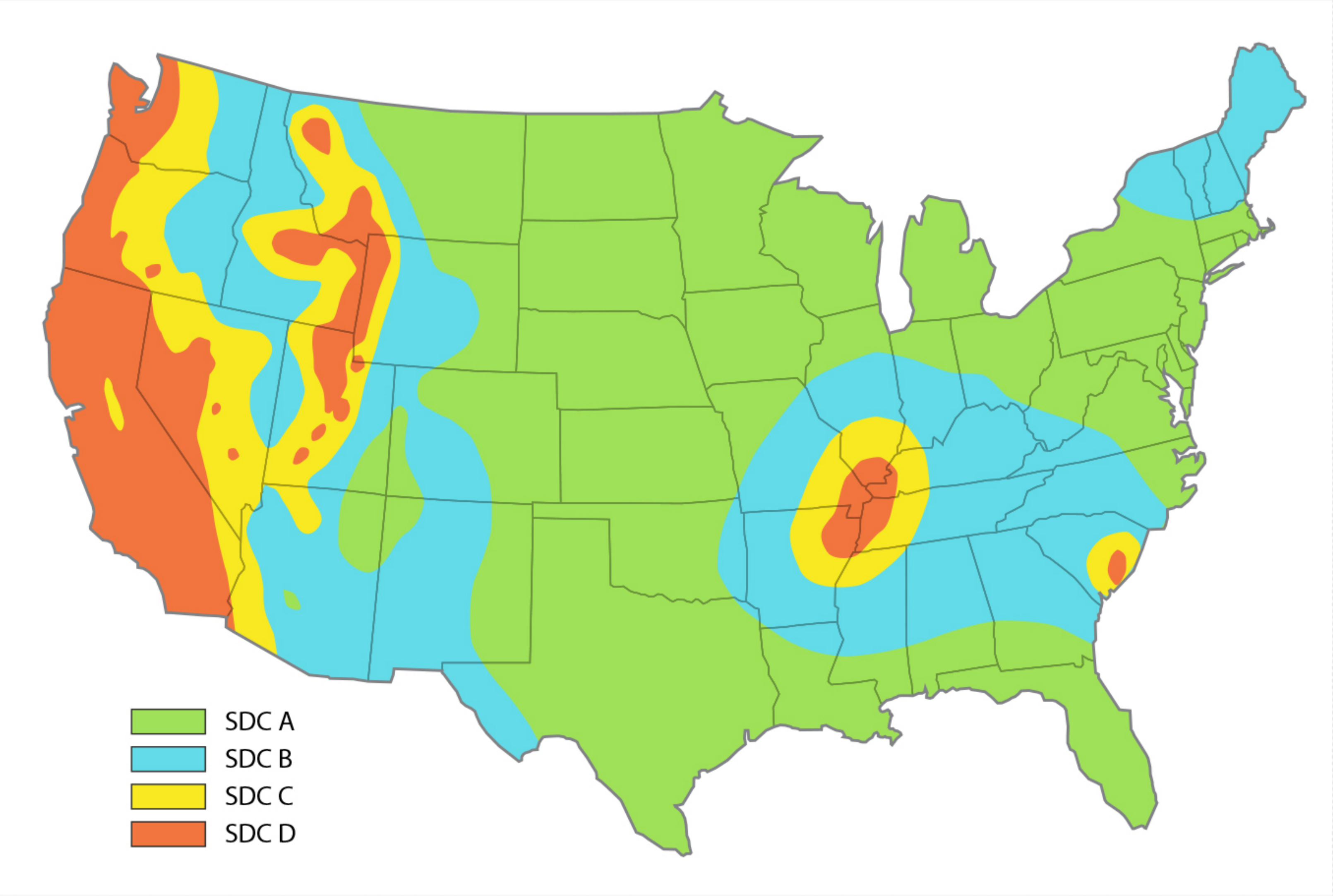
Transportation Research Board
Washington, DC

Organized by TRB Committee AFF50

Presentation Objectives

- Review typical seismic design performance objectives
- Identify how these are achieved with current design methodologies
- Explore how ABC connection types affect seismic design
- Consider where we are in the development of deployable technologies

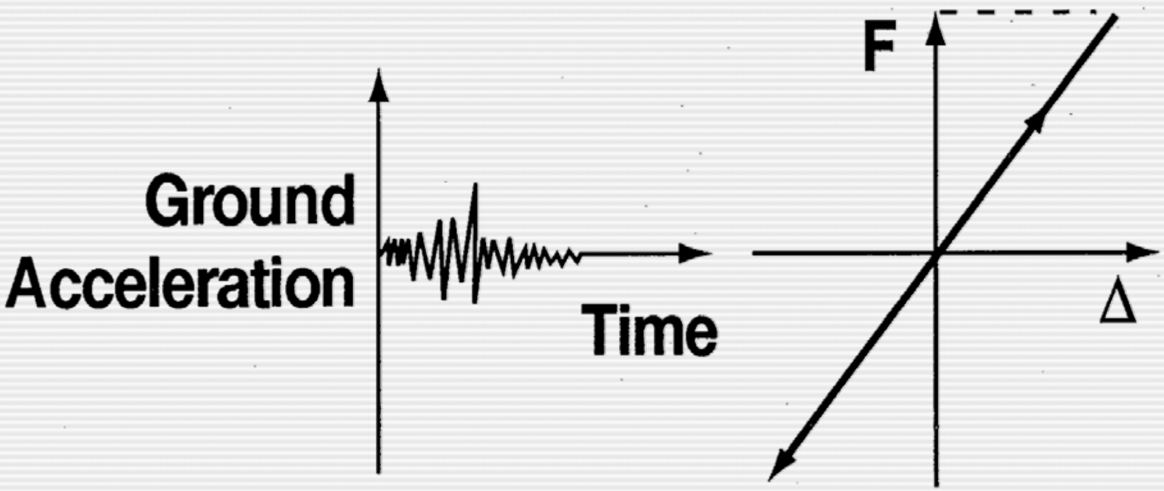
Seismic States for Site Class E



Three Principles of Seismic Design

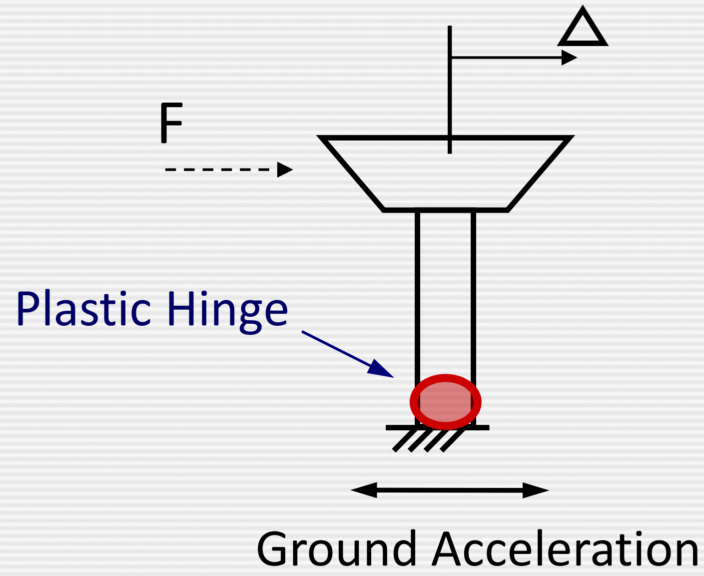
1. Seismic design allows damage to specific elements of bridges
2. Bridges are made damage-tolerant by careful detailing of these elements
3. All other elements of the bridge are capacity protected to prevent damage to them

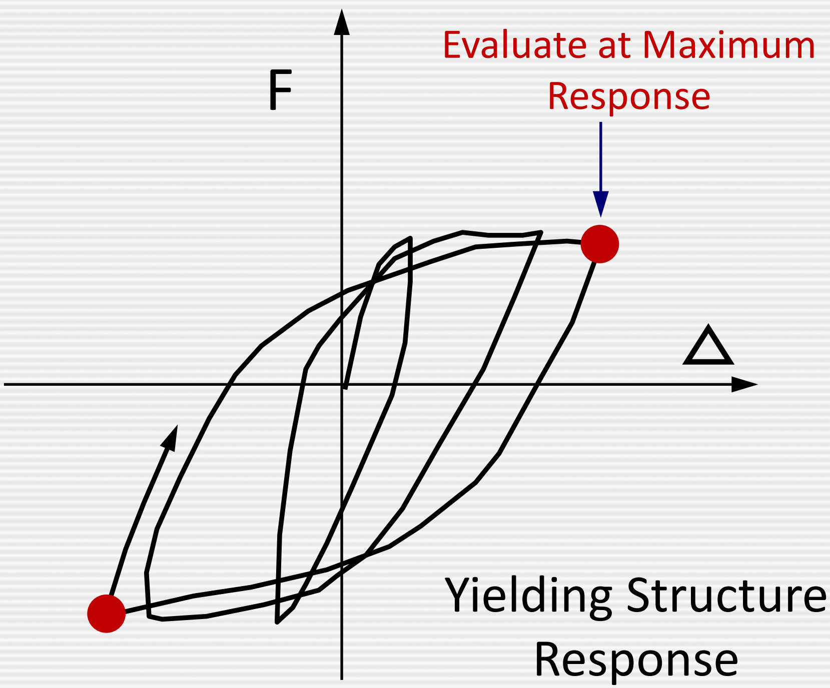
We Permit Earthquakes to Damage Bridges

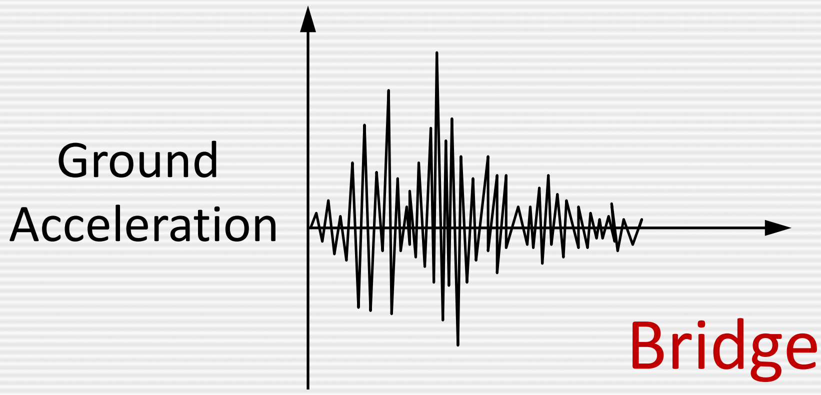


The forces induced if the structure is to remain undamaged can be too large to deal with, thus uneconomical

We Make Bridges Damage-Tolerant

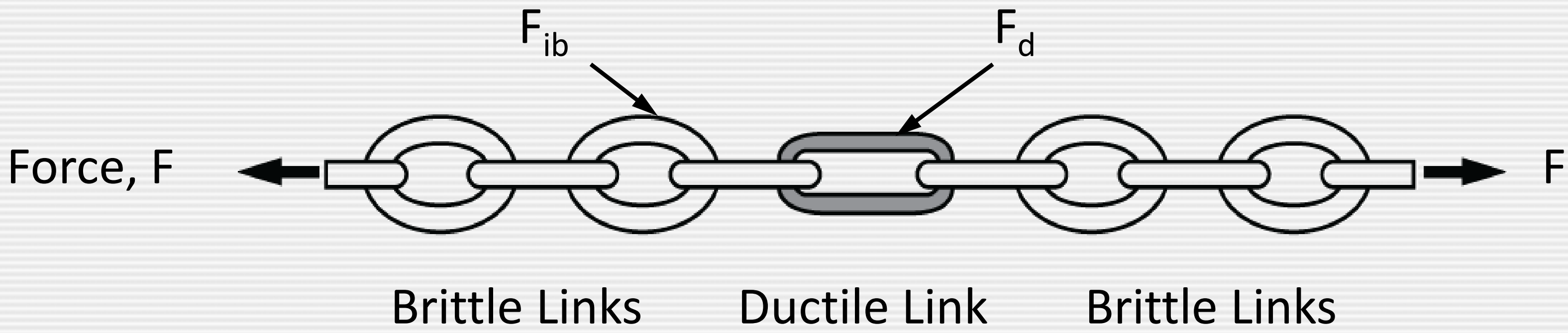


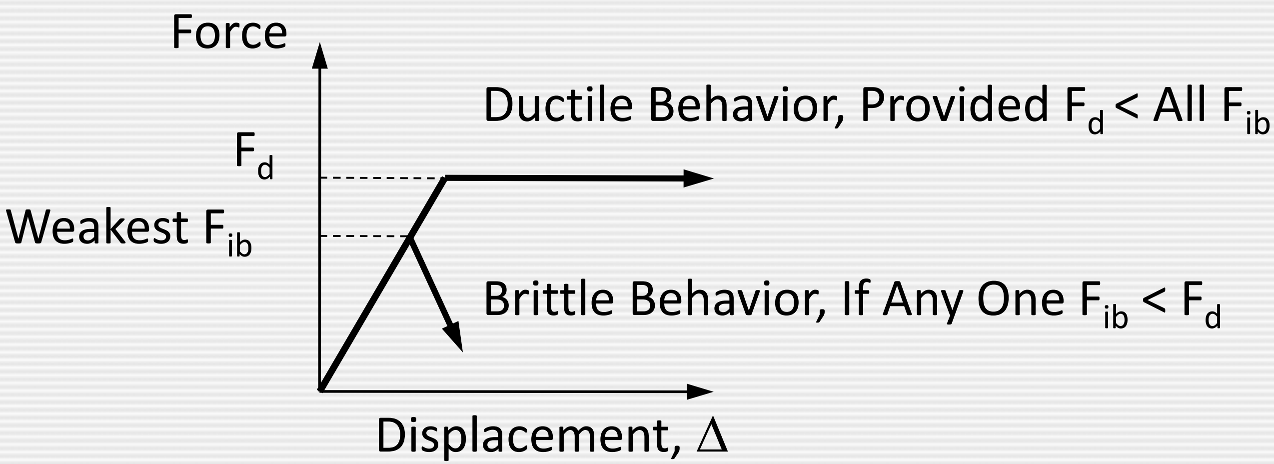




Bridges can be built to perform in a ductile manner

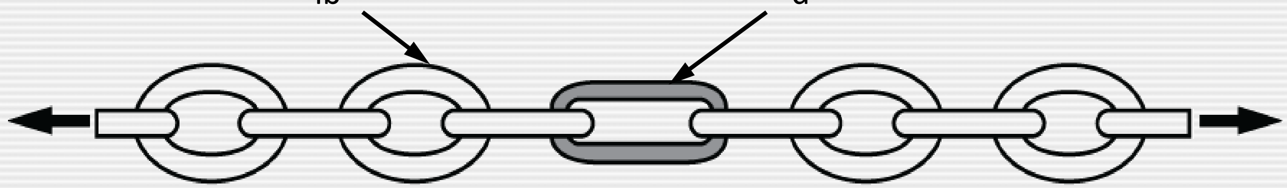
Chain Analogy - Capacity Protection

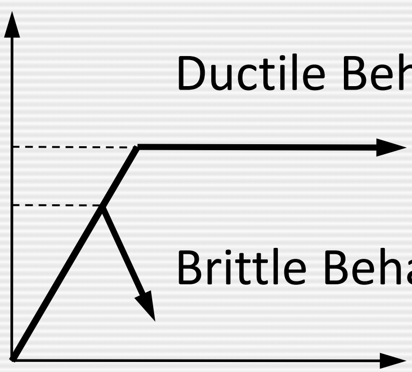




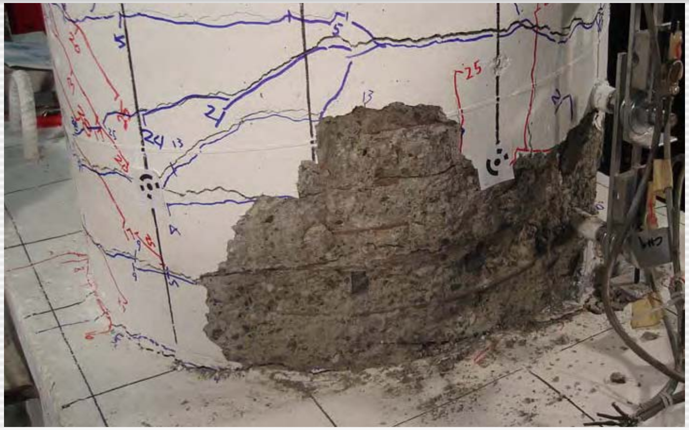
T. Paulay’s Chain Analogy

Chain Analogy - Capacity Protection



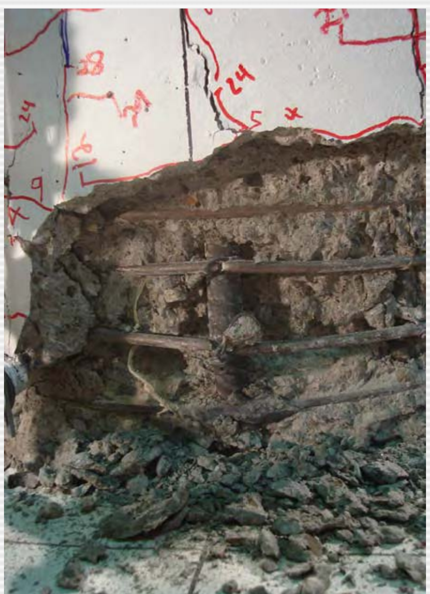


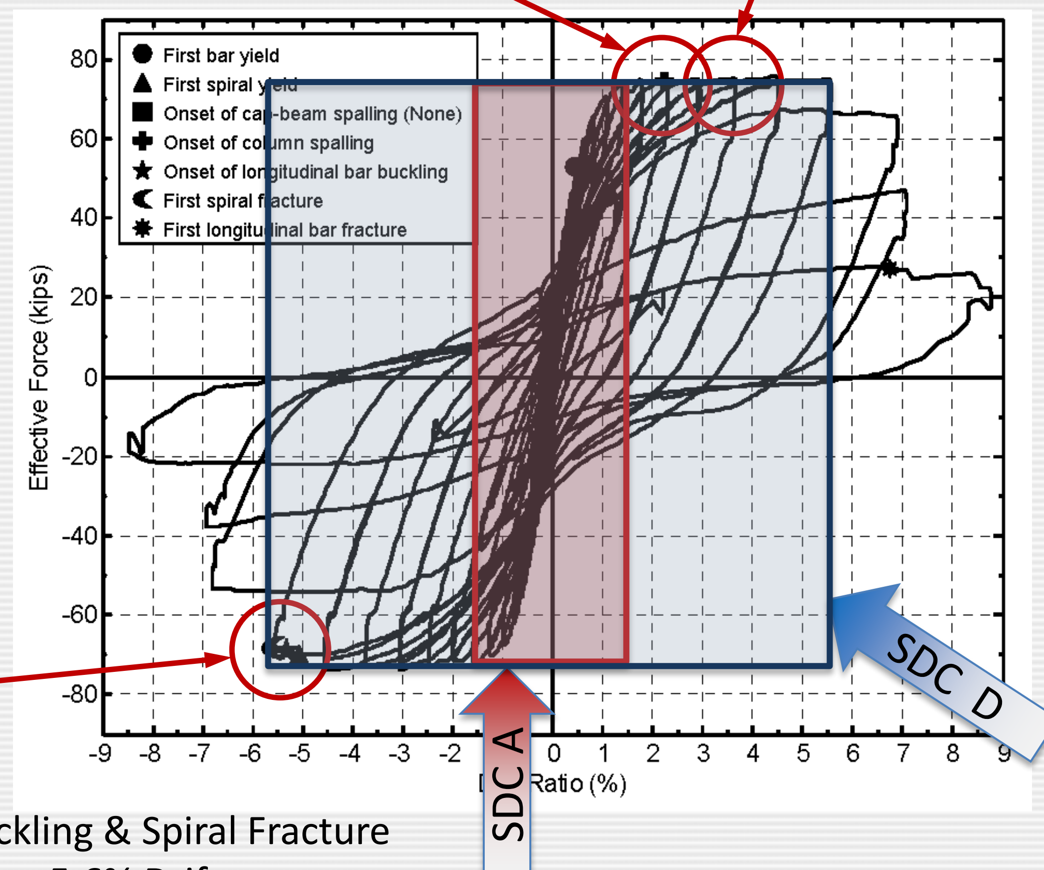
Damage from Cyclic Inelastic Loading



Spalling Condition at 3.7% Drift

Spalling Onset 2.2% Drift

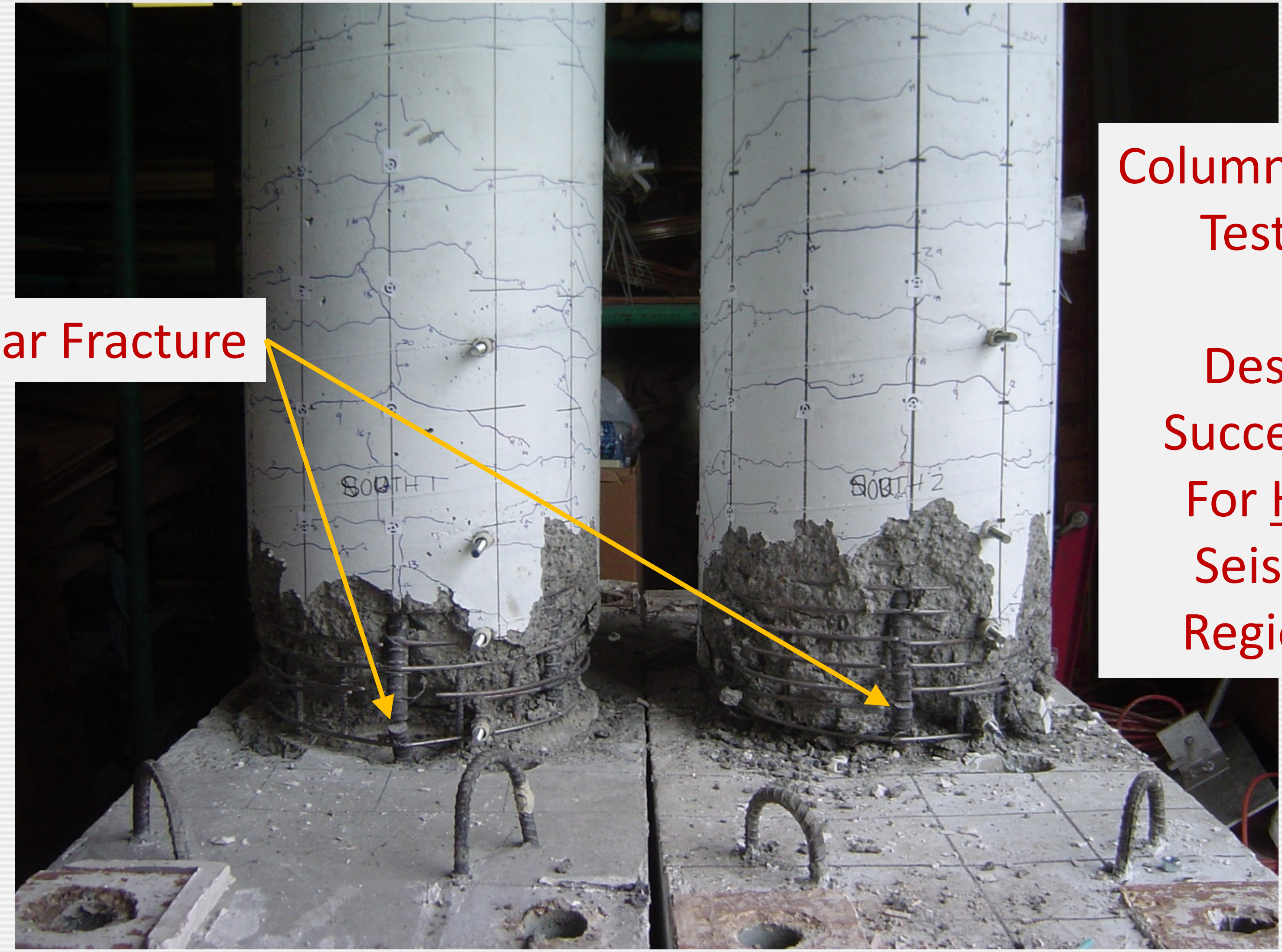




Bar Buckling & Spiral Fracture
5.6% Drift

Caltrans

Reduced-Scale ABC Column Tests



Bar Fracture

Columns After Testing

Design Successful For High Seismic Regions!

UW

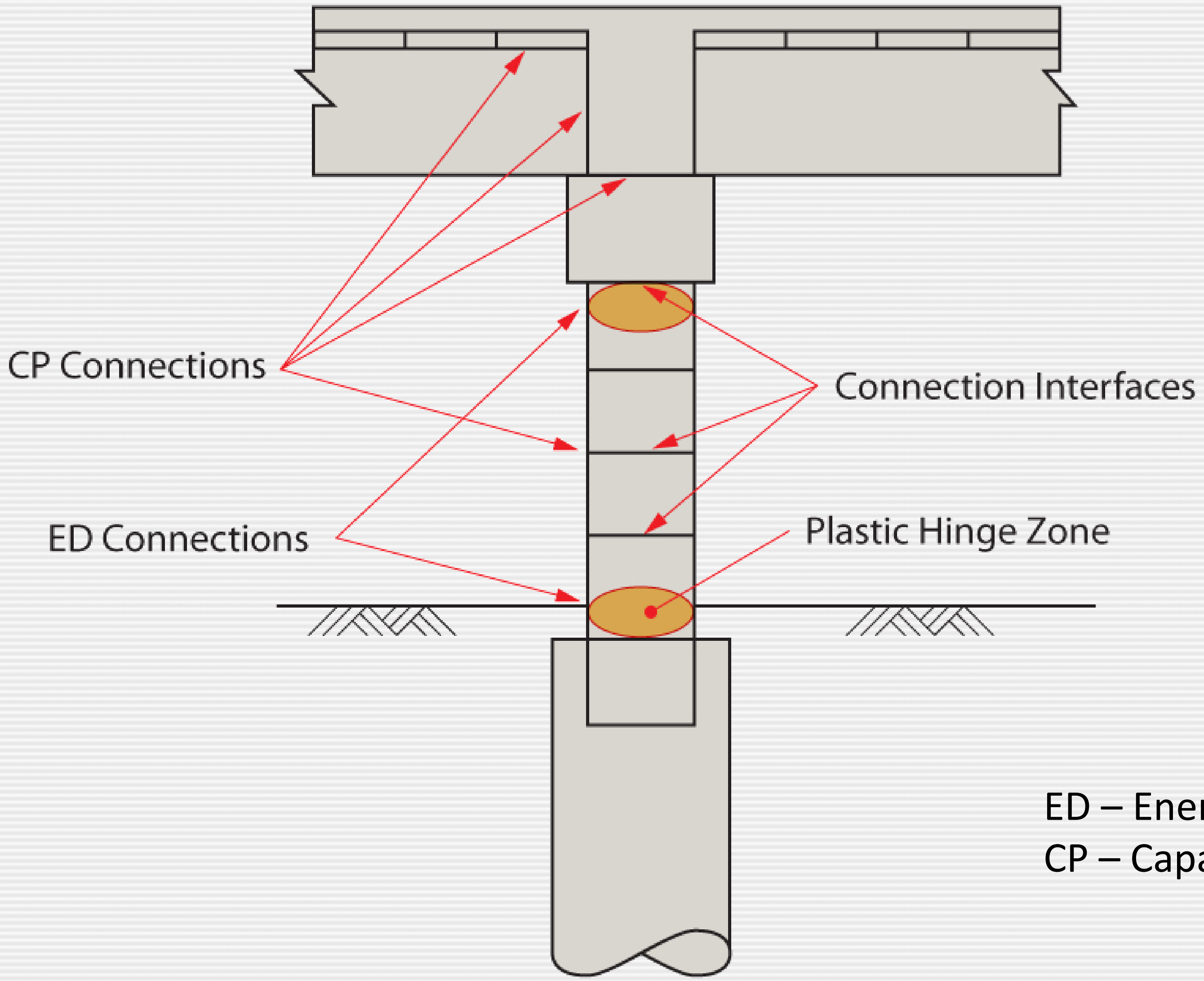
What's Special About Seismic Applications?

1. Continuity of load path under load reversals
2. Development of cyclic inelastic deformations
3. Maximum forces (moments) occur where we would like to connect prefabricated elements
4. Certain element/material behaviors may cause rapid loss of cyclic resistance
   - Local Buckling
   - Strain Concentrations
5. Detailing is important!

A Few Words on Continuity of Strength

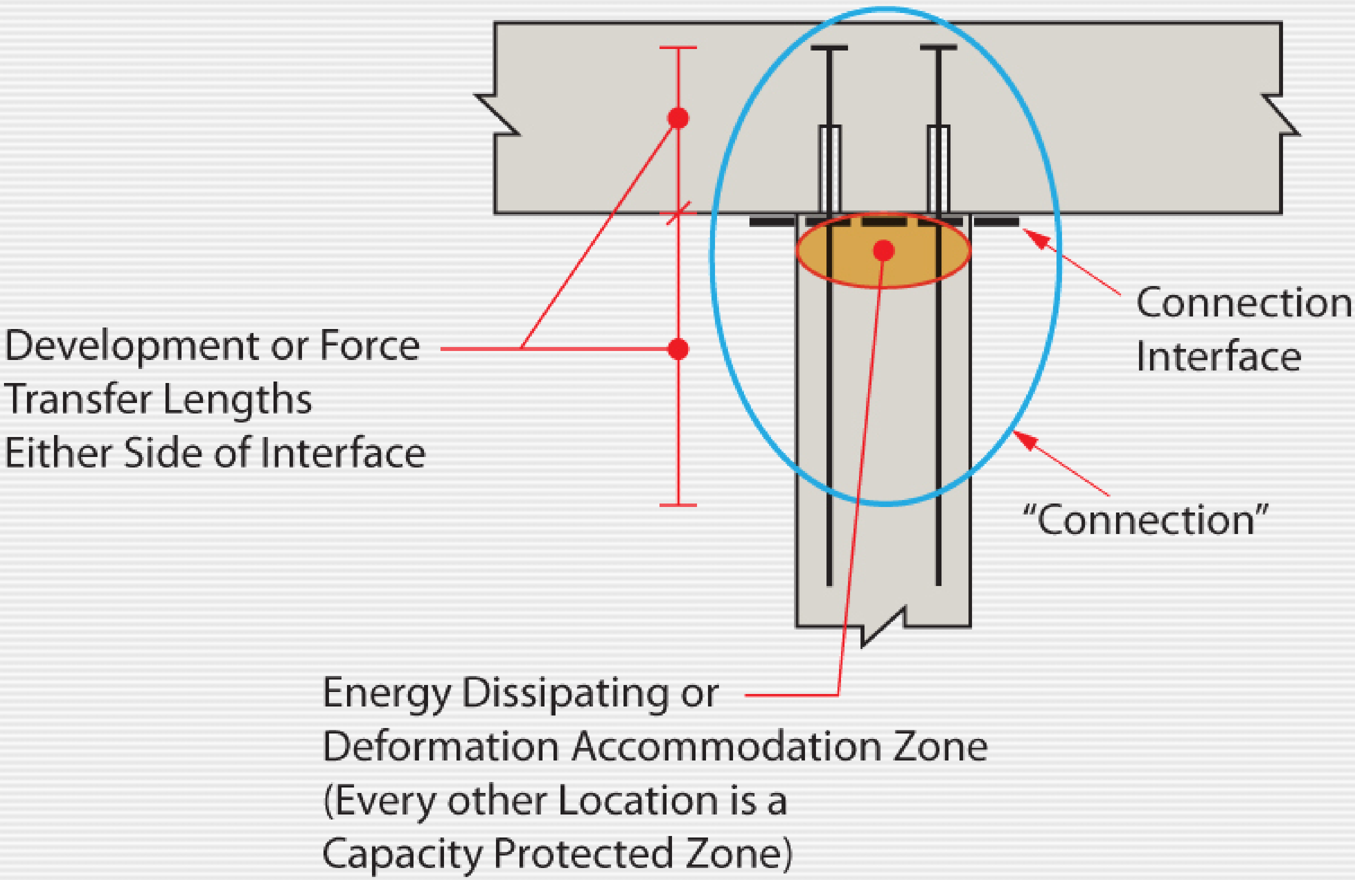
- In high seismic areas inelastic ductility is required; thus clearly all members must have sufficient strength to form the intended plastic mechanism.
- In low seismic (non-seismic) areas, continuity of strength is still required, just not the ductility (or deformation capacity).
- In low-seismic areas, there still needs to be lateral capacity commensurate with the minimum member strength requirements (e.g. 0.7 or 1 % minimum steel, etc)

Example ABC Connection Locations in a Bridge

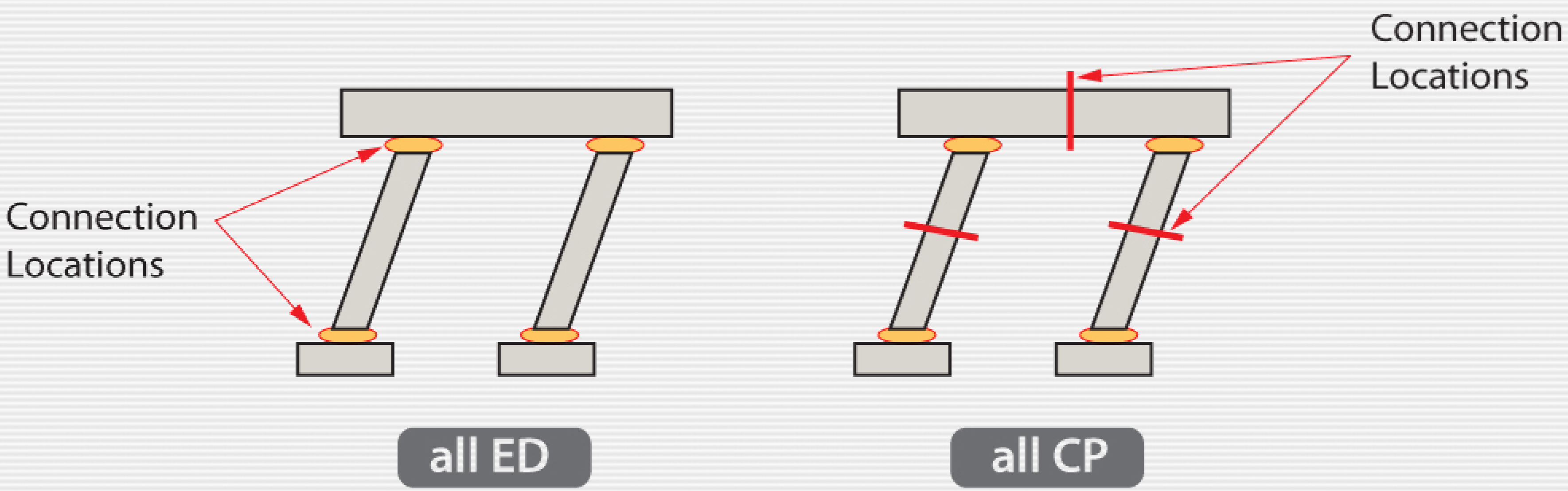


ED – Energy Dissipating
CP – Capacity Protected

Definition of ABC-Type Connection



Where are the connections?



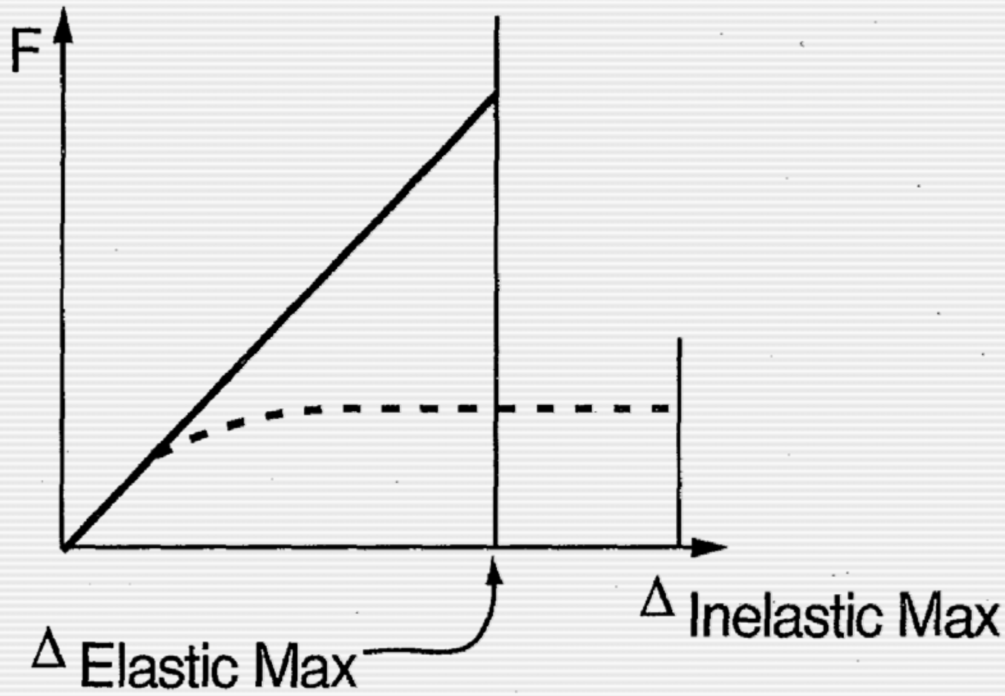
ED – Energy Dissipating
CP – Capacity Protected

Basic Steps of Seismic Design

Step	Basic Steps for Seismic Design
1	Determine Seismic Input
2	Establish Design Procedures
3	Identify the Earthquake Resisting System and Global Design Strategy
4	Perform Demand Analysis
5	Design and Check Earthquake Resisting Elements (Ductile or Other)
6	Capacity Protect the Remaining Elements

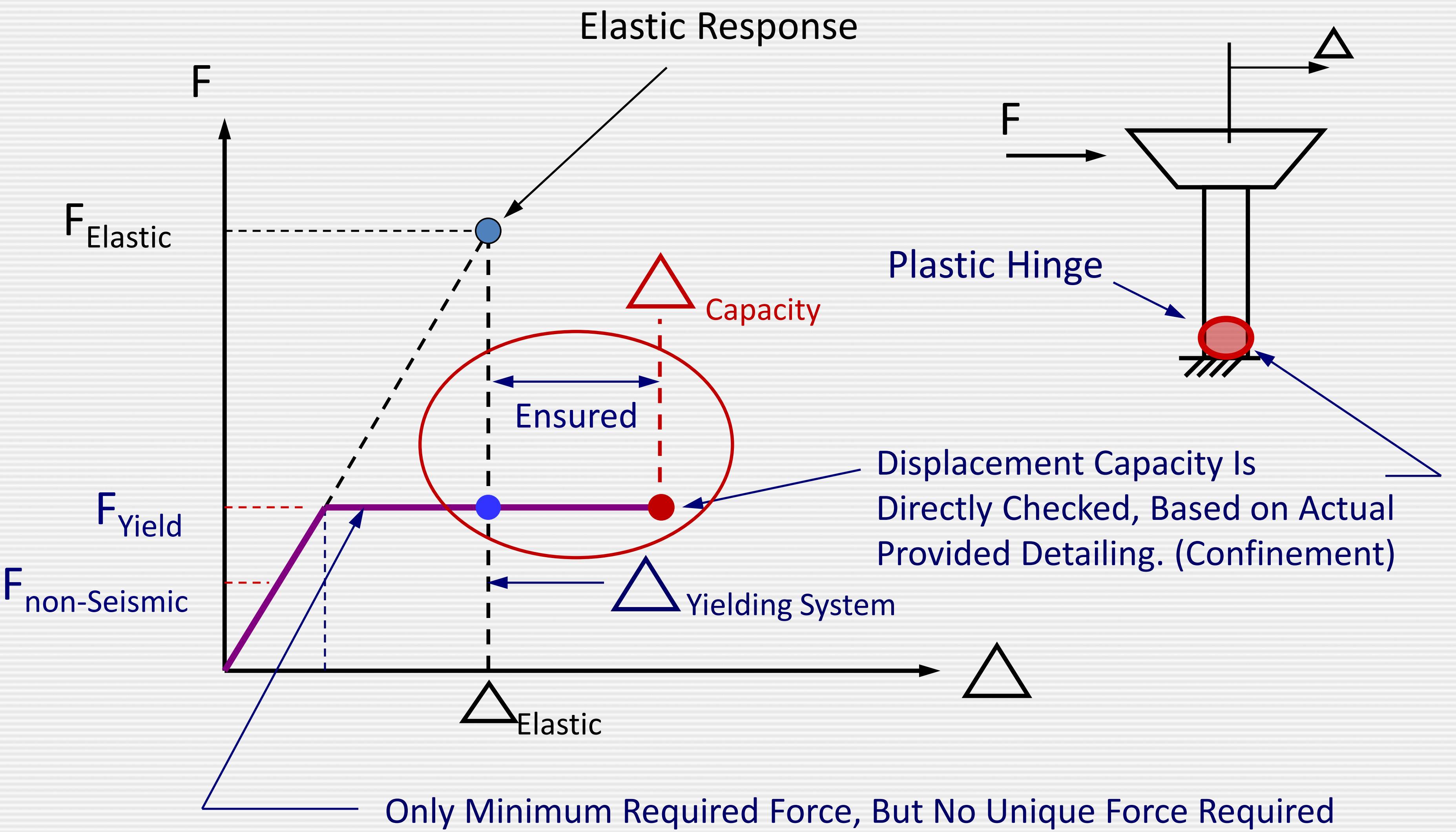
We Typically Analyze Bridges Elastically

How can we estimate the inelastic displacement of the system?



Can use linear elastic analysis to predict nonlinear displacements!

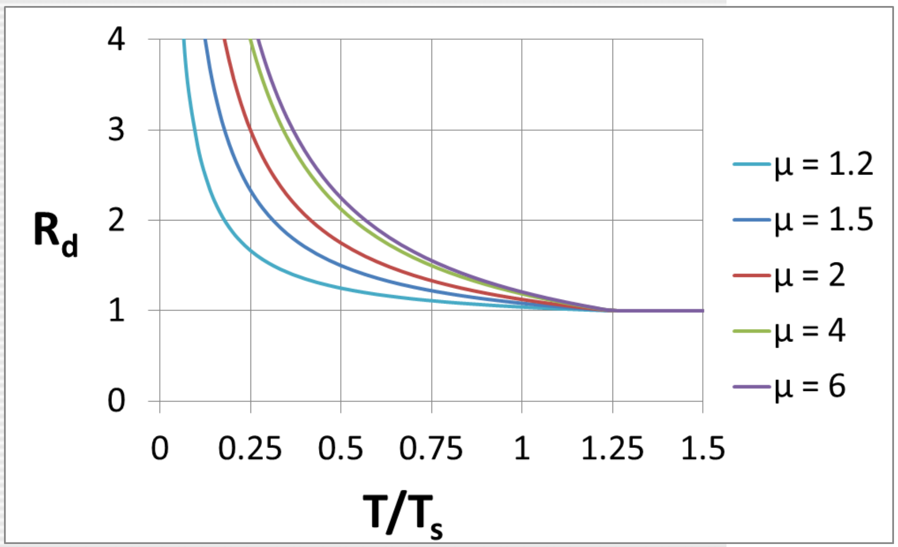
Displacement-Based Method (DBM)

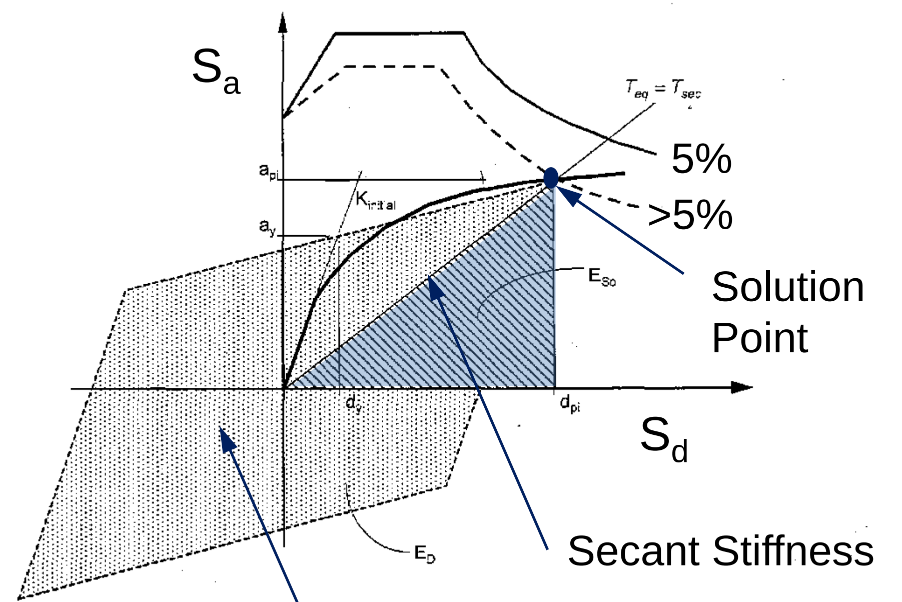


Inelastic to Elastic Response

Two common methods:

"Coefficient" Method (AASHTO – LS and GS)	Substitute Structure Method (Capacity Spectrum - Isolation)





T = Fundamental Period of System
T_s = "Corner" of Response Spectrum

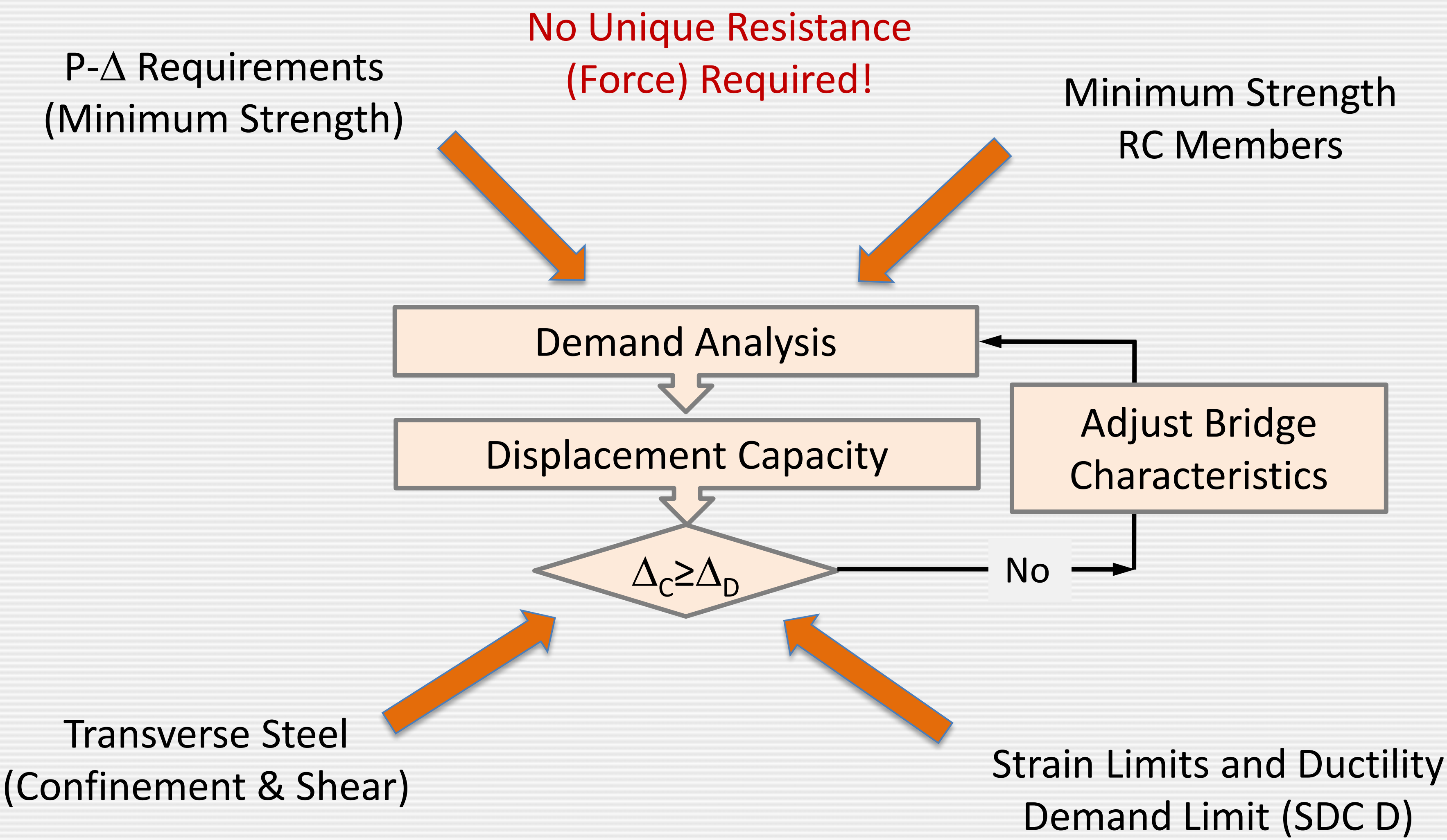
Area give effective damping – based on hysteretic behavior

ABC Seismic Systems

Two types of systems:

- System 1) Emulative behavior of normal RC systems
  - Use current AASHTO Coefficient Method for demand (generally conservative of all such systems)
- System 2) Completely different hysteretic behavior
  - Improved behavior (e.g. re-centering)
  - Improved/controlled damping
  - Controlled damage
  - Use Capacity Spectrum Method for demand (still under development)

Ductile Design Activity - DBM



What's Special About Seismic Applications?

1. Continuity of load path under load reversals
2. Development of cyclic inelastic deformations
3. Maximum forces (moments) occur where we would like to connect prefabricated elements
4. Certain element/material behaviors may cause rapid loss of cyclic resistance
   - Local Buckling
   - Strain Concentrations
5. Detailing is important!

Grouped Similar Connection Types

Generally Behavior is Emulative of RC

- Bar Couplers
- Grouted Ducts
- Pocket Connections
- Socket Connections
- Integral Connections (Connections Super to Piers)

Non-Emulative of RC

- Emerging Technologies
  - Prestress Tendons in Tandem with Deformed Bars
  - Shape Memory Alloy and ECC
  - Replaceable Elements (Either Emulative or Not)

Grouped Similar Connection Types

Generally Behavior is Emulative of RC

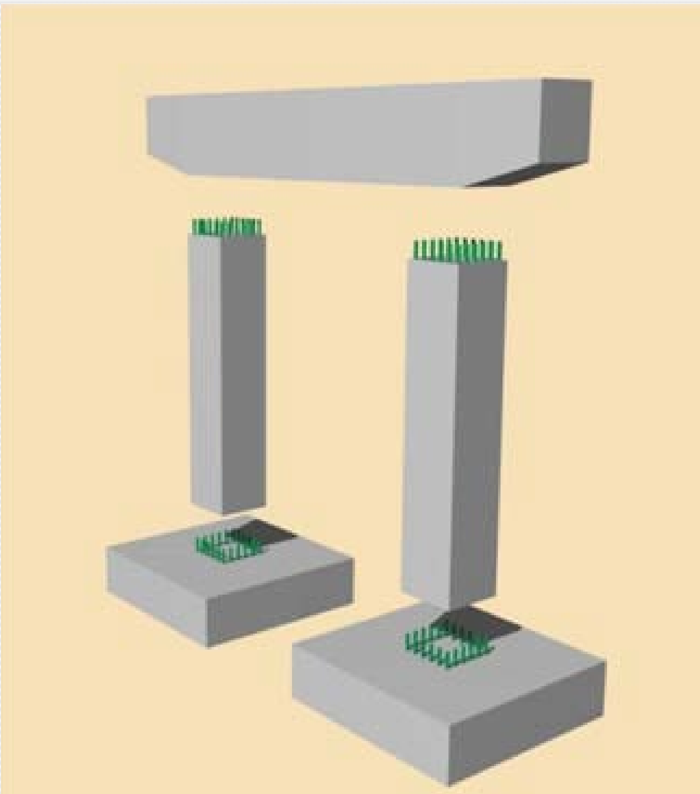
- Bar Couplers
- Grouted Ducts
- Pocket Connections
- Socket Connections
- Integral Connections (Connections Super to Piers)

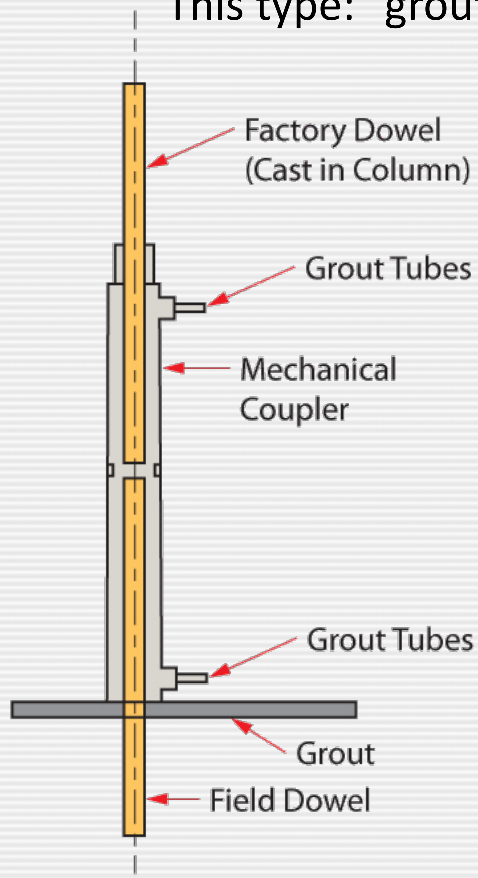
Non-Emulative of RC

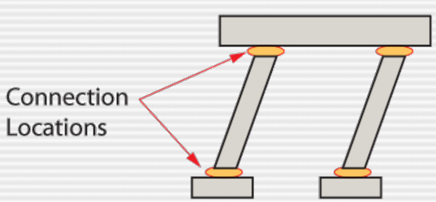
- Emerging Technologies
  - Prestress Tendons in Tandem with Deformed Bars
  - Shape Memory Alloy and ECC
  - Replaceable Elements (Either Emulative or Not)

Bar Coupler Connections

This type: “grouted-sleeve connection”



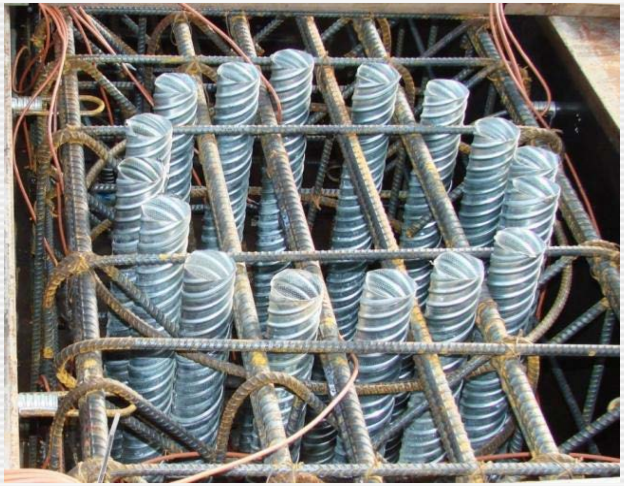




Note that the stiffening presence and “non-yielding” length of the coupler can substantially decrease the ductility of the connection relative to continuous reinforcing bars.

all ED

Grouted Duct Connections



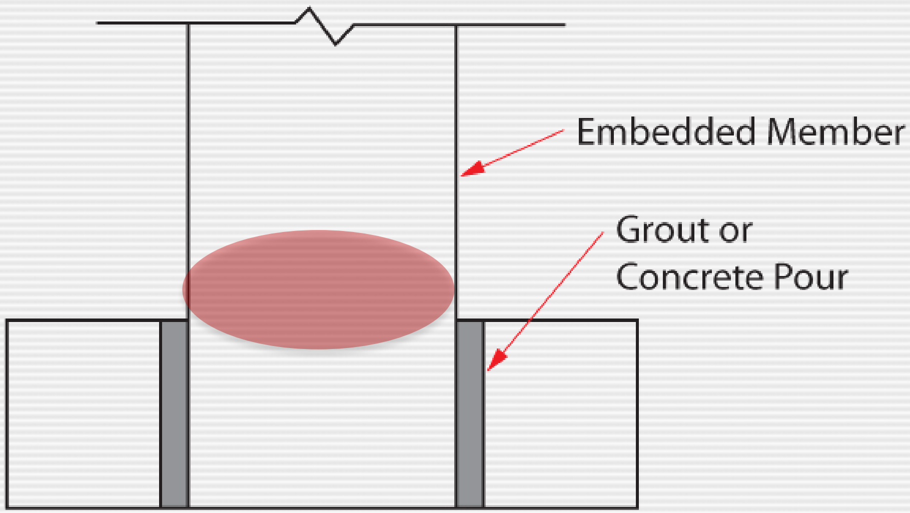
NCHRP 12-74

WSDOT

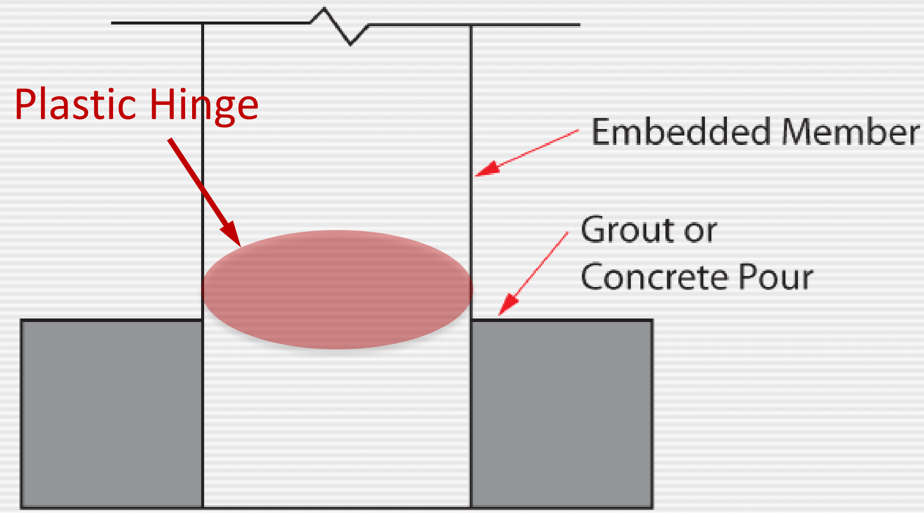
Pocket Connections

NCHRP 12-74

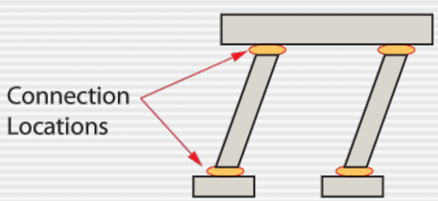
Member Socket Connections



Embedded Column
In Blocked out Footing



Embedded Column
In CIP Footing



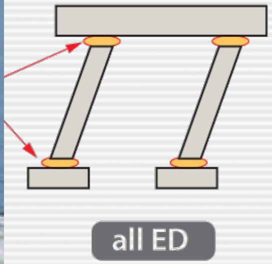
Note that these connections can be made generally "emulative" of reinforced concrete connections.

all ED

Socket Connection Using Block Outs

Steel Pile Bent
with Precast Cap Beam

BergerABAM

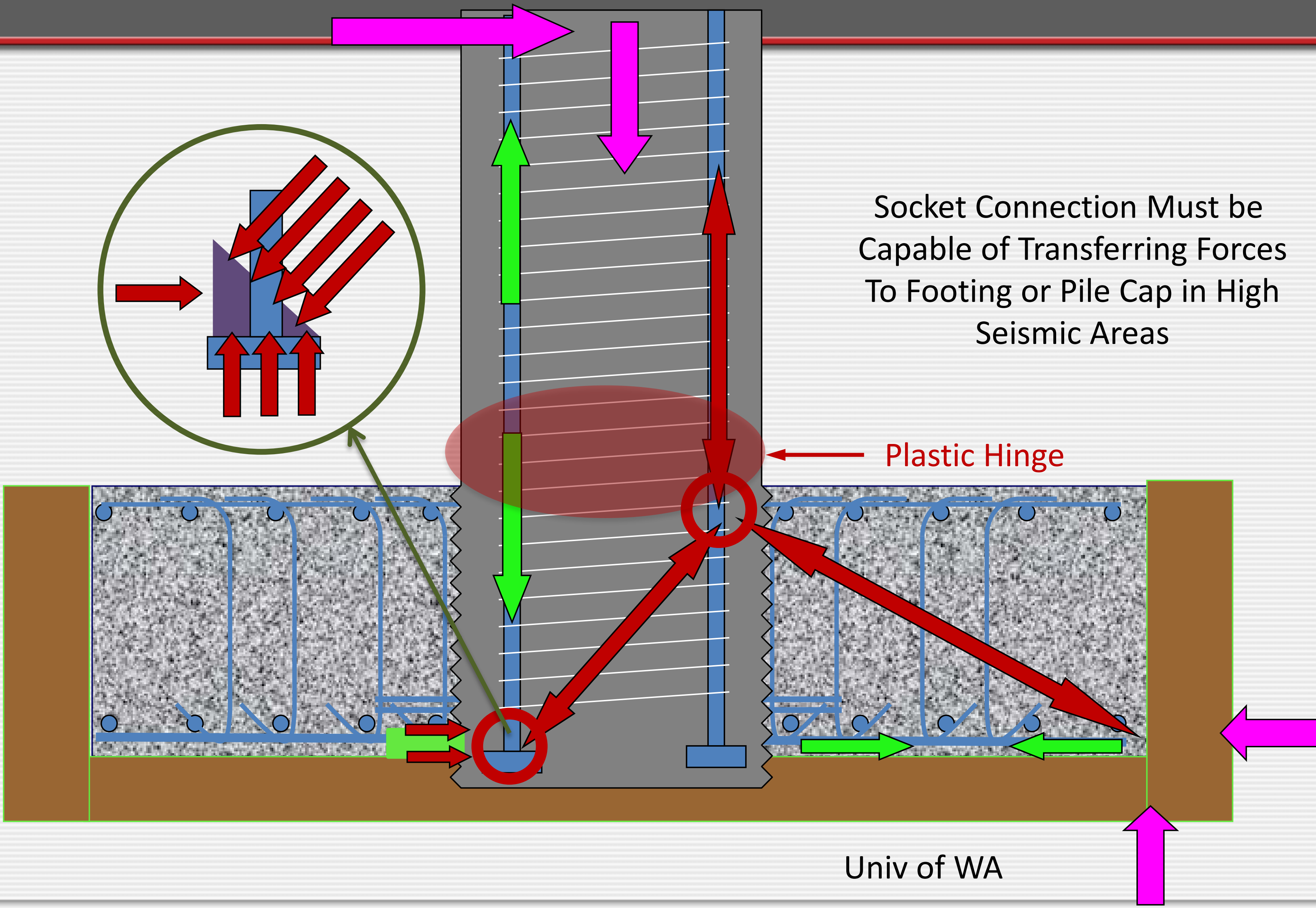


Socket Connections in CIP Footing

Precast Column with Cast-in-Place Footing

BergerABAM

Socket Connection – Internal Forces

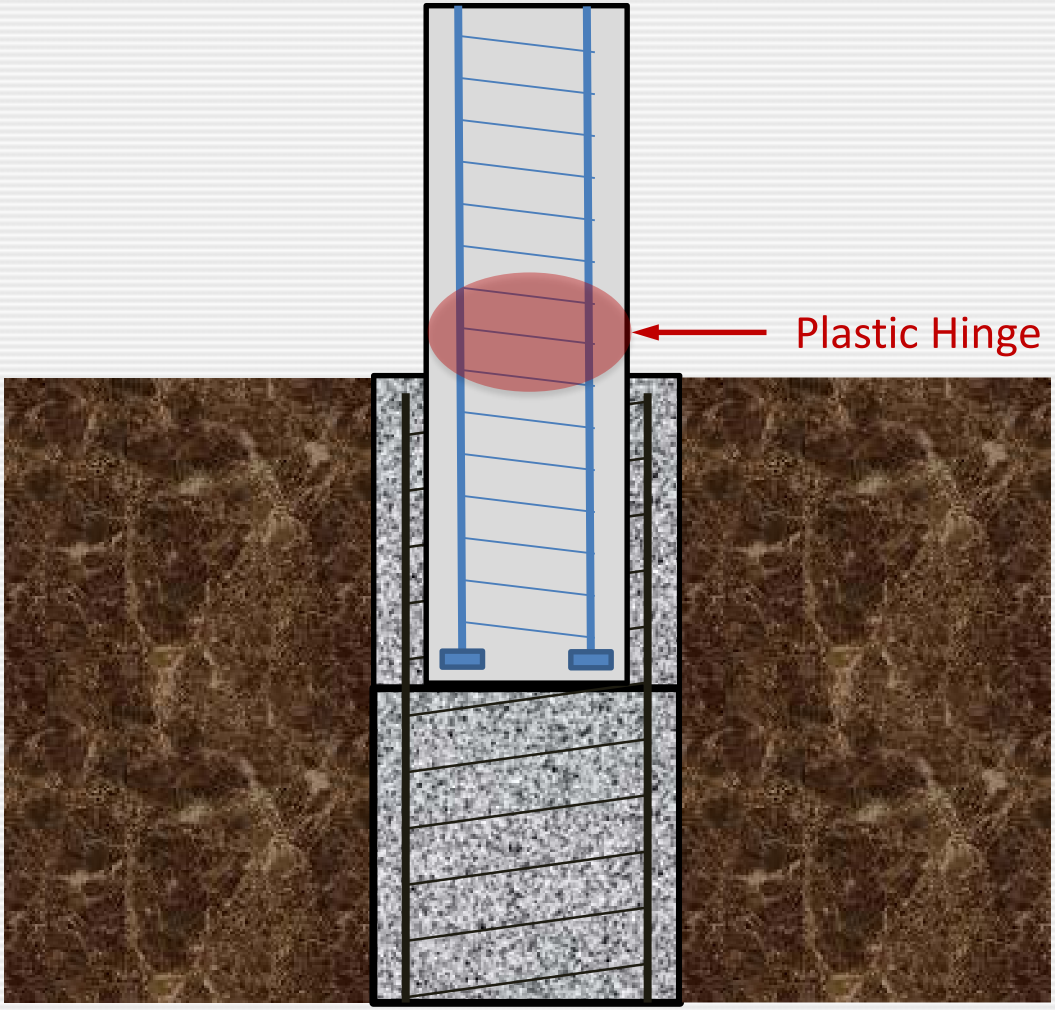


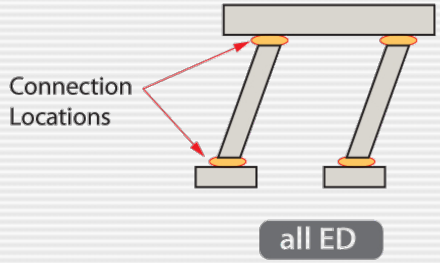
Precast Column Socket Connection - Lateral Load Test

Footing undamaged

Univ of WA

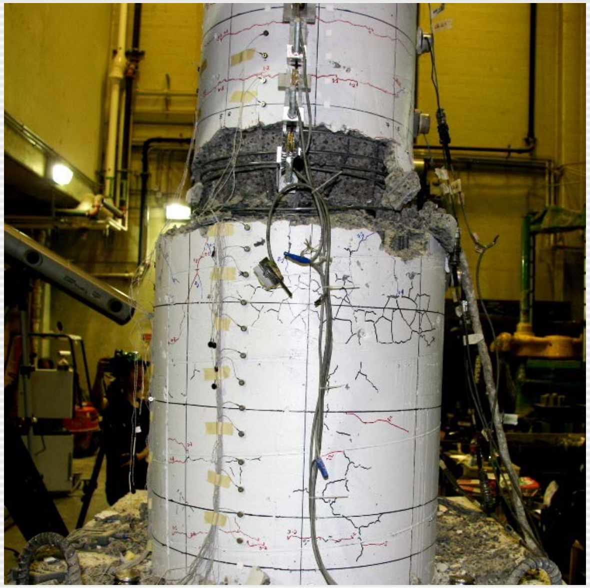
Drilled-Shaft Socket Connection Concept





Column-Shaft Tie Reinforcement

Shaft Transverse Reinforcement Must Be
Capable of Resisting Splitting Forces in
High Seismic Areas

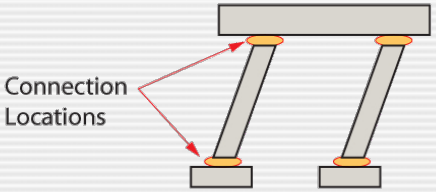


University of Washington

Integral Connection Systems

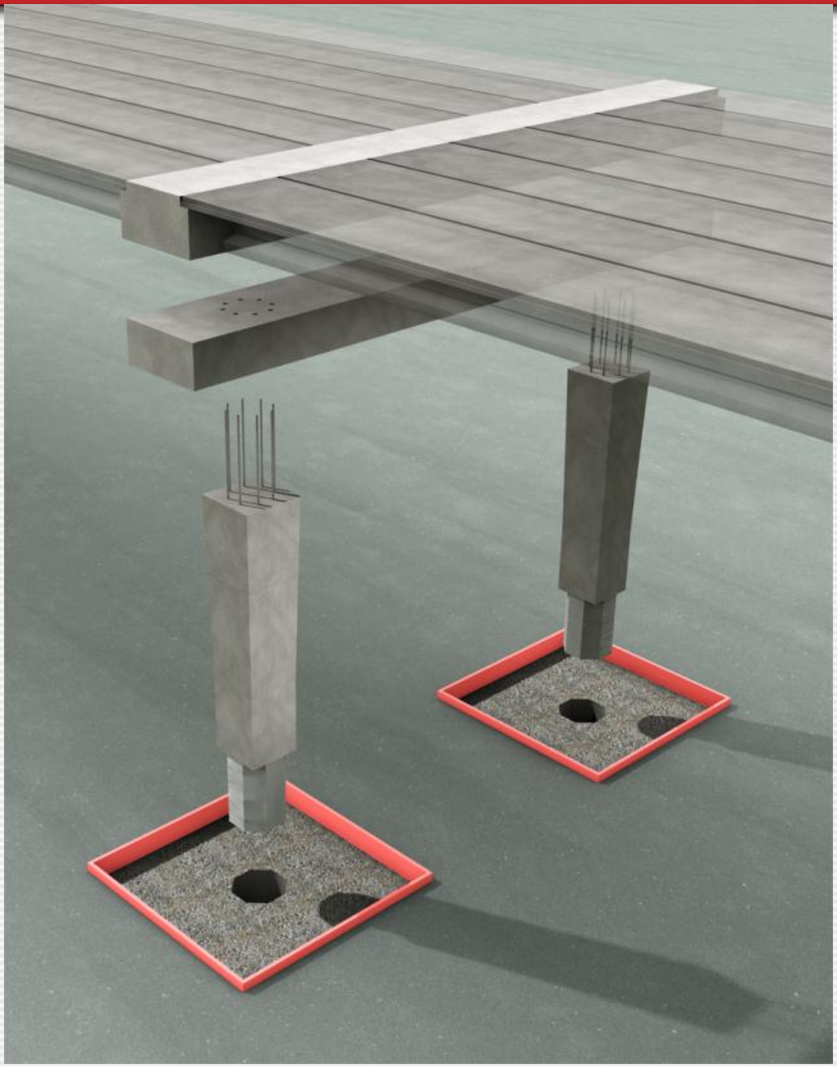
Two-Stage CIP Cap Beam with Precast Prestressed Girder Superstructure

Girders are made continuous over bents for live and lateral loads.



all ED

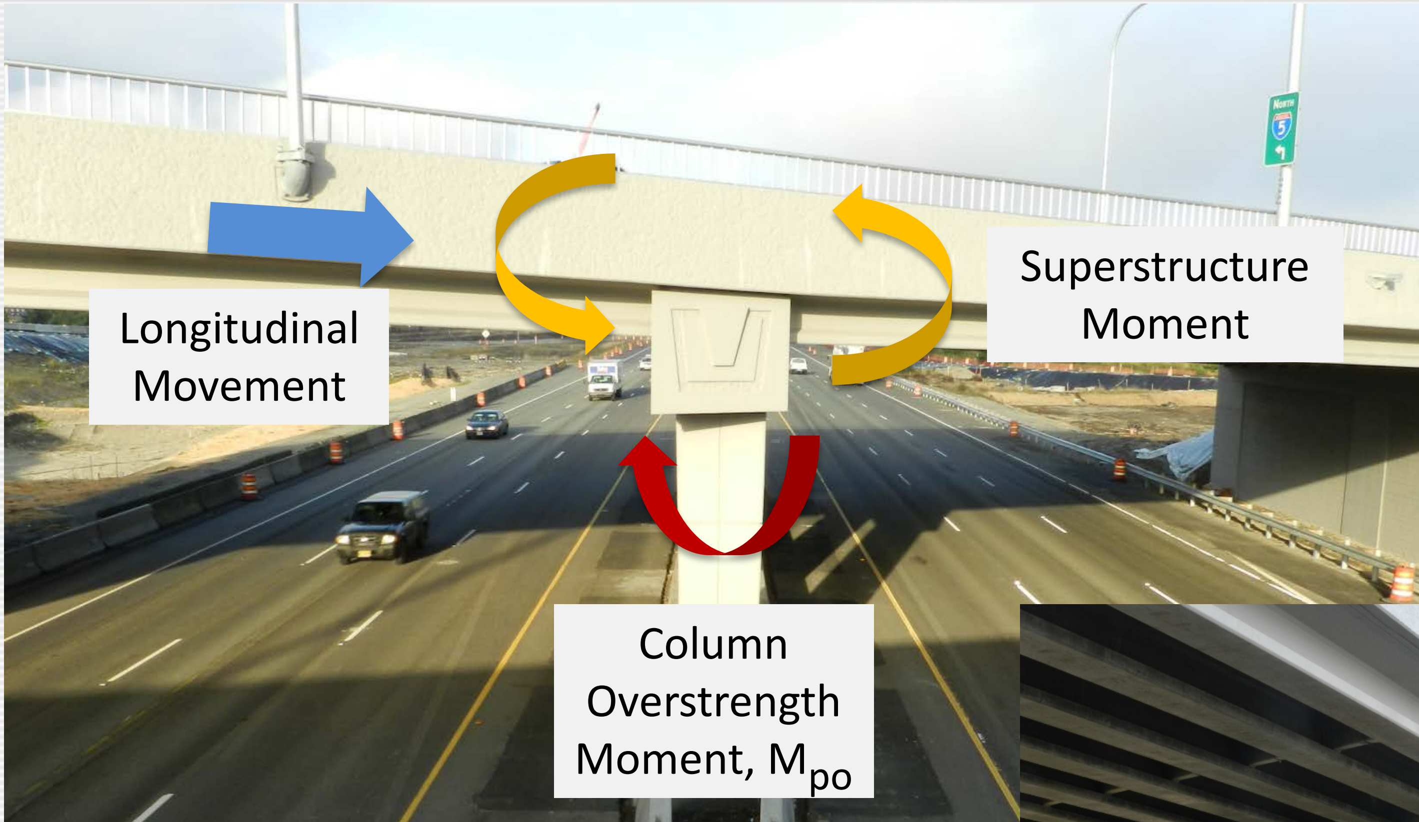
Precast Bent System for High Seismic Regions



- Member socket connection at base (ED)
- Few, but large, bars at precast cap connection (ED)
- Two-stage cap
- Upper stage CIP
- Girders integral with combined lower and upper stages of cap (CP)

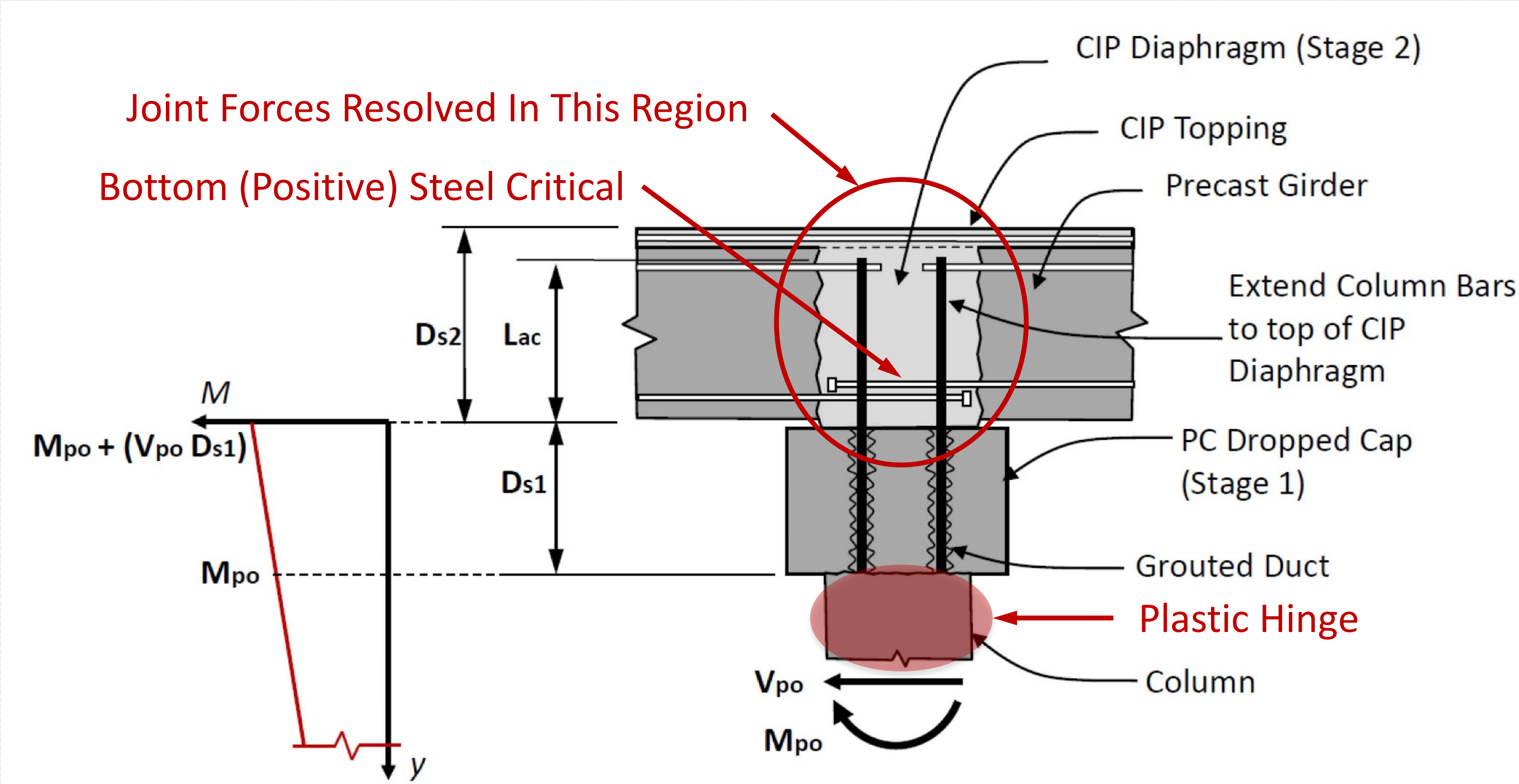
WSDOT HfL Project

Longitudinal Loading – Moments at Two-Stage Cap



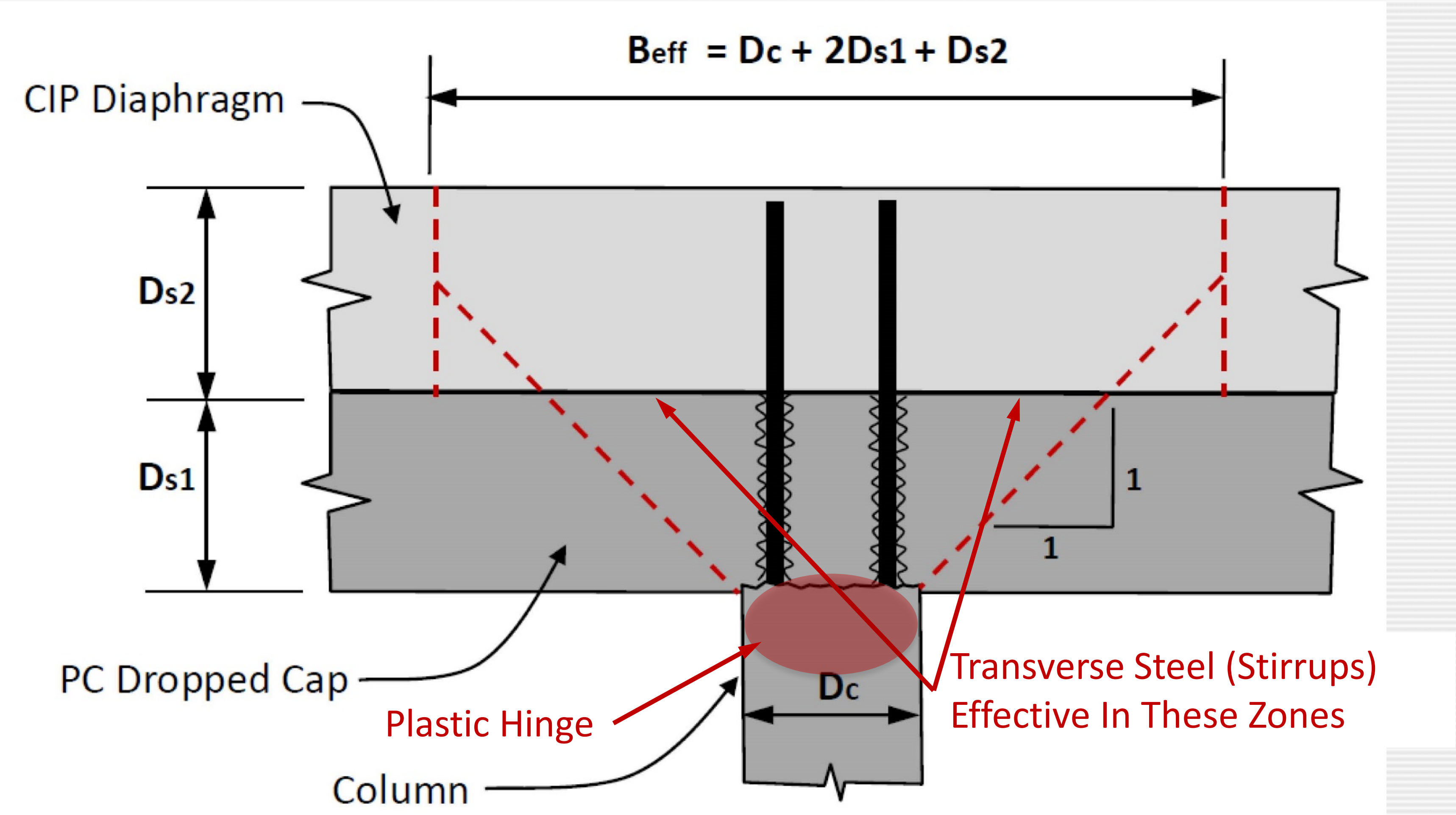
Column Longitudinal Moment Resisted Entirely in Upper Stage (Superstructure)

Longitudinal Joint Considerations



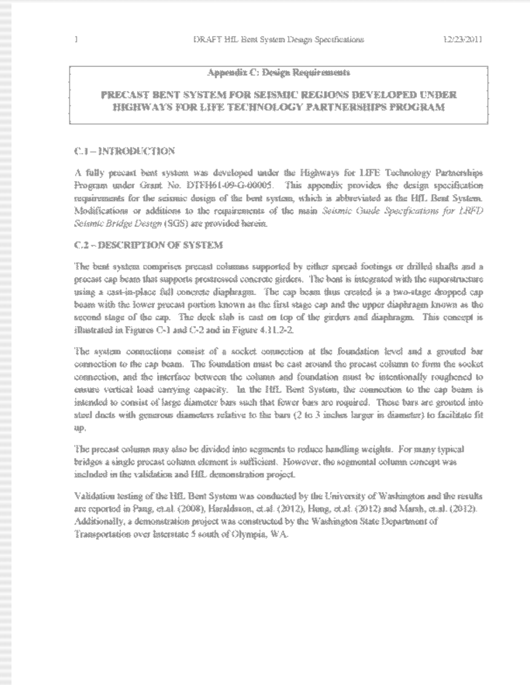
Design Example in Highways for LIFE Reports

Two-Stage Cap Longitudinal Joint Width



Design Example in Highways for LIFE Reports

Precast Pier System: Demonstration Project and Design Specifications



1 DRAFT HfL Bent System Design Specifications 12/23/2011

Appendix C: Design Requirements

PRECAST BENT SYSTEM FOR SEISMIC REGIONS DEVELOPED UNDER HIGHWAYS FOR LIFE TECHNOLOGY PARTNERSHIPS PROGRAM

C.1 – INTRODUCTION

A fully precast bent system was developed under the Highways for LIFE Technology Partnerships Program under Grant No. DTFH61-09-G-00005. This appendix provides the design specification requirements for the seismic design of the bent system, which is abbreviated as the HfL Bent System. Modifications or additions to the requirements of the main *Seismic Guide Specifications for LRFD Seismic Bridge Design* (SGS) are provided herein.

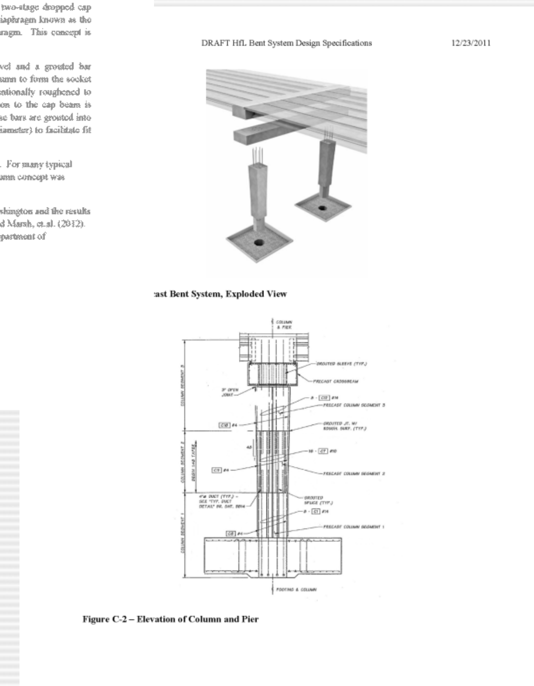
C.2 – DESCRIPTION OF SYSTEM

The bent system comprises precast columns supported by either spread footings or drilled shafts and a precast cap beam that supports prestressed concrete girders. The bent is integrated with the superstructure using a cast-in-place full concrete diaphragm. The cap beam thus created is a two-stage dropped cap beam with the lower precast portion known as the first stage cap and the upper diaphragm known as the second stage of the cap. The deck slab is cast on top of the girders and diaphragm. This concept is illustrated in Figures C-1 and C-2 and in Figure 4.31.2-2.

The system connections consist of a socket connection at the foundation level and a grouted bar connection to the cap beam. The foundation must be cast around the precast column to form the socket connection, and the interface between the column and foundation must be intentionally roughened to ensure vertical load carrying capacity. In the HfL Bent System, the connection to the cap beam is intended to consist of large diameter bars such that fewer bars are required. These bars are grouted into steel ducts with generous diameters relative to the bars (2 to 3 inches larger in diameter) to facilitate fit up.

The precast column may also be divided into segments to reduce handling weights. For many typical bridges a single precast column element is sufficient. However, the segmental column concept was included in the validation and HfL demonstration project.

Validation testing of the HfL Bent System was conducted by the University of Washington and the results are reported in Pang, et.al. (2008), Haraldsson, et.al. (2012), Hung, et.al. (2012) and Marsh, et.al. (2012). Additionally, a demonstration project was constructed by the Washington State Department of Transportation over Interstate 5 south of Olympia, WA.



DRAFT HfL Bent System Design Specifications 12/23/2011

:ast Bent System, Exploded View

Figure C-2 – Elevation of Column and Pier

WSDOT, BergerABAM, UW – Highways for LIFE Technology Partnerships Program

Grouped Similar Connection Types

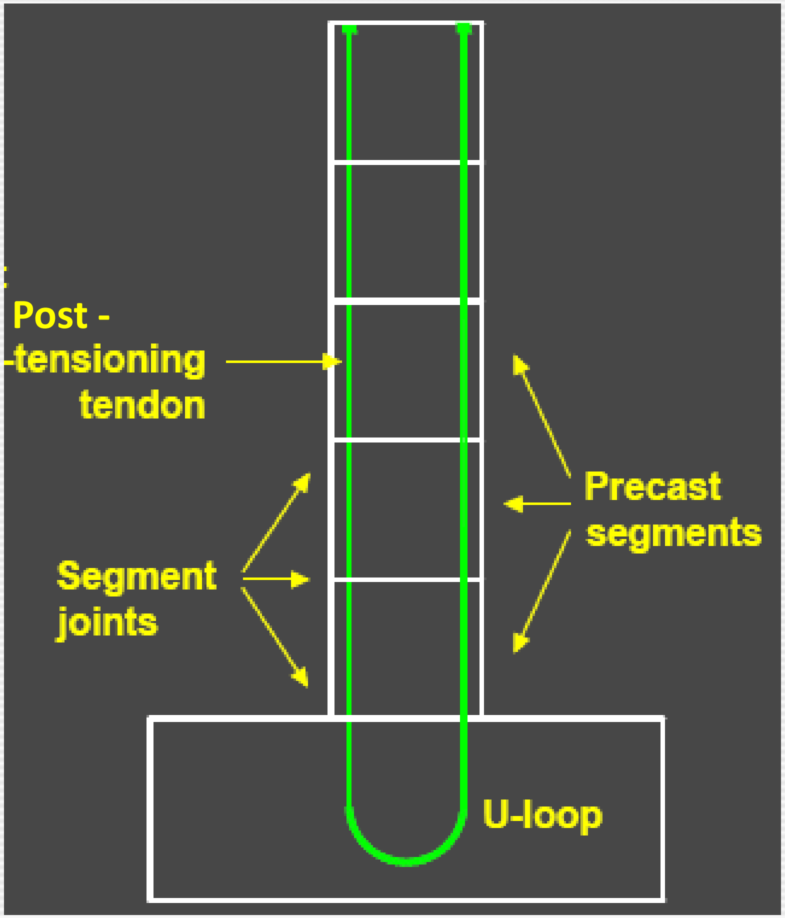
Generally Behavior is Emulative of RC

- Bar Couplers
- Grouted Ducts
- Pocket Connections
- Socket Connections
- Integral Connections (Connections Super to Piers)

Non-Emulative of RC

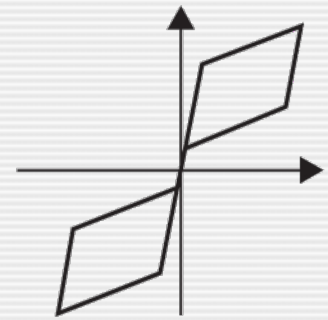
- Emerging Technologies
  - Prestress Tendons in Tandem with Deformed Bars
  - Shape Memory Alloy and ECC
  - Replaceable Elements (Either Emulative or Not)

Hybrid Connections / Non-Emulative Systems

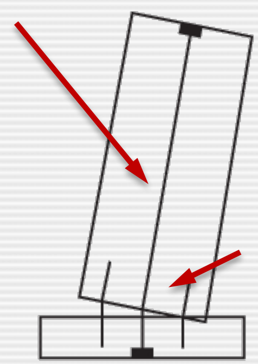


MCEER / SUNY Buffalo

Force – Displacement
Energy Dissipation & Re-centering



PT provides re-centering



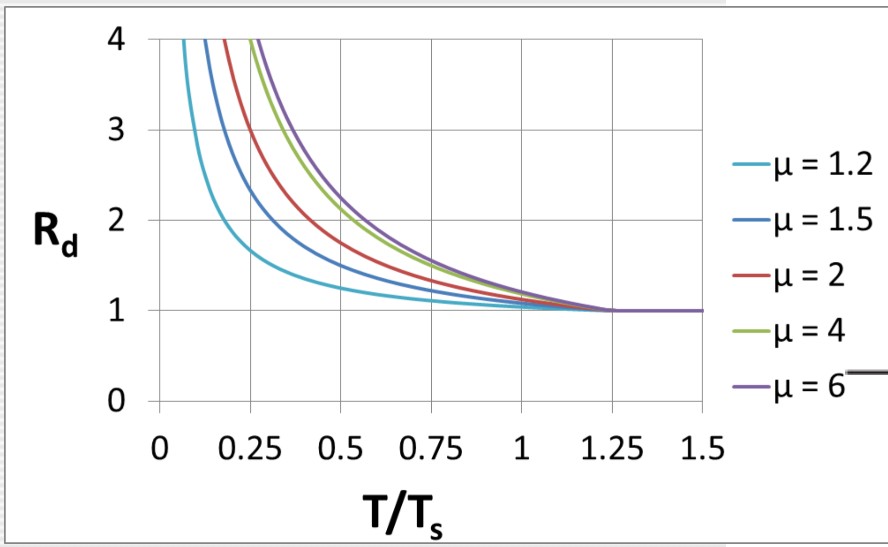
Rebar provides energy dissipation

This is but one such system. A number of such systems are under development.

Recall - Inelastic to Elastic Response

Two common methods:

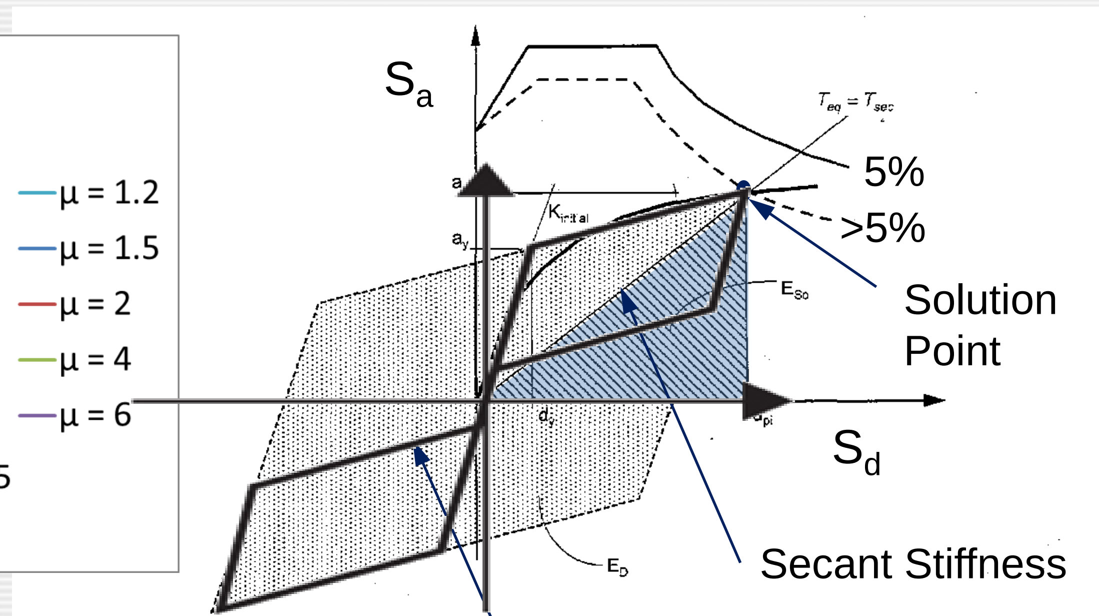
"Coefficient" Method (AASHTO – LS and GS)



T = Fundamental Period of System

T_s = "Corner" of Response Spectrum

Substitute Structure Method (Capacity Spectrum - Isolation)



Area gives effective damping – based on hysteretic behavior

Technology Readiness Level (TRL)

Conceptual Example

Technology Readiness Level (TRL)		% of development complete			
TRL	Description	0-25	25-50	50-75	75-100
1	Concept exists				
2	Static strength predictable				infill
3	Non-seismic deployment				"
4	Analyzed for seismic loading				"
5	Seismic testing of components		catch-up required		
6	Seismic testing of subassemblies		"		
7	Design & construction guidelines				
8	Deployment in seismic area				
9	Adequate performance in EQ		advancement		

TRL Concept Developed by NASA

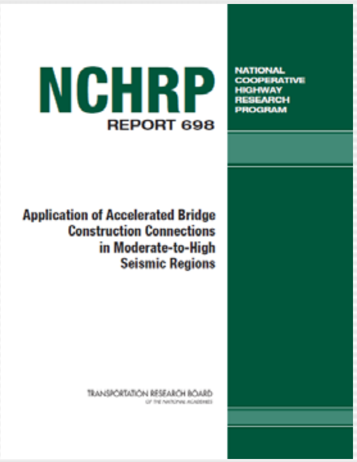
General Observations

- All systems require some:
  - ***Infill*** = additional knowledge
  - ***Advancement*** = higher level of readiness
  - ***Catch-up*** (some do) = knowledge gaps that need closing

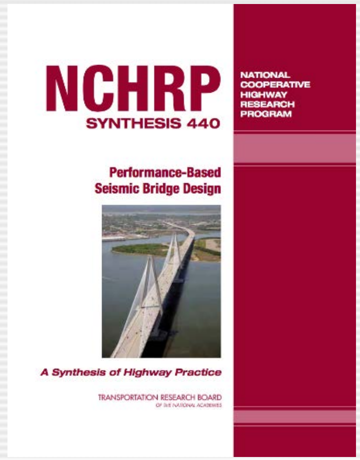
- No systems have endured the design earthquake and performed adequately; thus no TRL 9 systems.

National Cooperative Highway Research Program

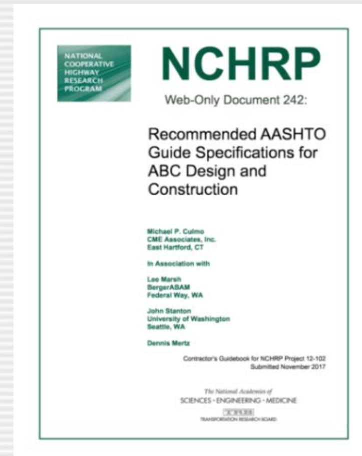
Published Documents:



ABC Synthesis - 698



PBSD Synthesis - 440



ABC Recommended Specs
Report 242
Recently adopted by AASHTO*

* Expect ongoing and future tests will lead to improvements

Specifications in Development: NCHRP 12-106 – Performance-Based Seismic Design (PBSD) Specifications

Thank You!

Systems for Accelerated Bridge Construction (ABC) in Seismic Regions: Overview

John Stanton
University of Washington

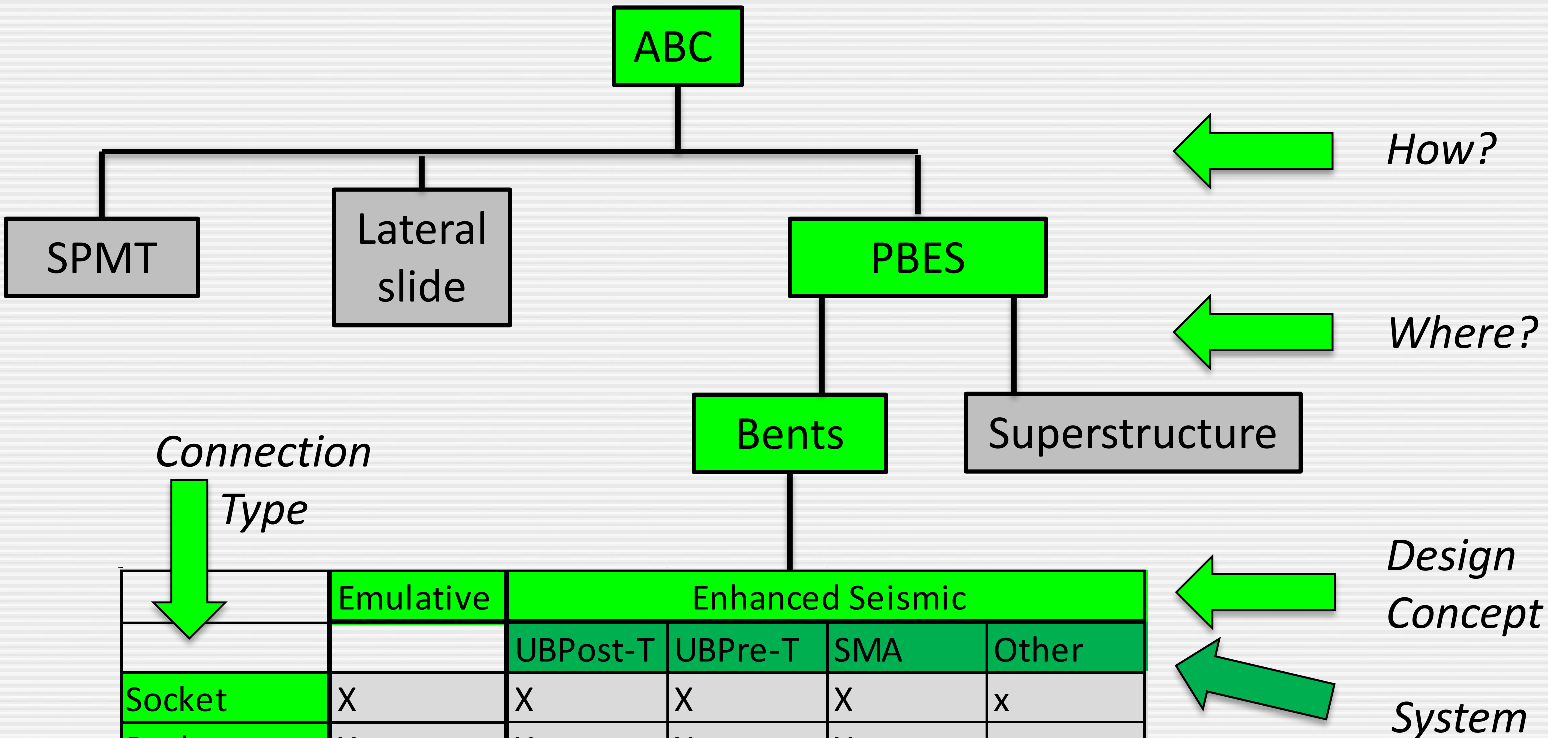
11 July 2018

Webinar organized by TRB Committee AFF50

Outline

- Decision tree of systems and connections.
- Connections that can be used with many systems.
- Selected systems for enhanced seismic performance.

Decision Tree



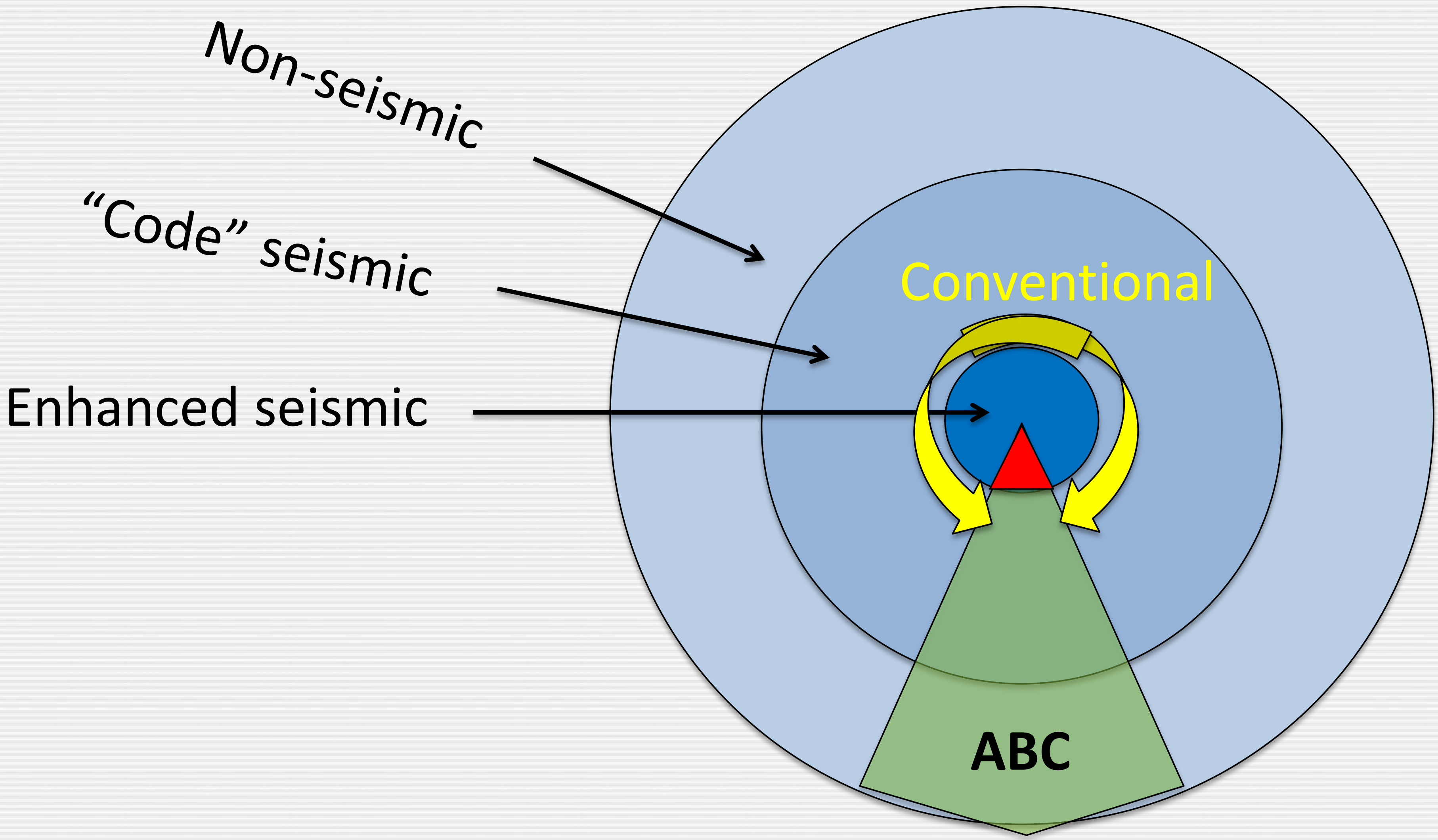
	Emulative	Enhanced Seismic			
		UBPost-T	UBPre-T	SMA	Other
Socket	X	X	X	X	x
Pocket	X	X	X	X	x
Grouted duct	X	X	X	X	x
Other	x	x	x	x	x

SPMT = **S**elf **P**ropelled **M**odular **T**ransporter
PBES = **P**recast **B**ridge **E**lements and **S**ystems
UBPre-T = **U**n**B**onded **Pre**-**T**ensioned
SMA = **S**hape **M**emory **A**lloy

ABC & Enhanced Seismic Performance

- ABC using prefabricated elements requires a design approach different from that of conventional construction.
- ABC vs conventional construction for seismic:
  - Can we get ***as good*** performance with ABC?
    - ❖ *Present approach: Life Safety.*
  - Can we get ***better*** performance with ABC? e.g.
    - ❖ *No residual drift.*
    - ❖ *Low damage.*

Design for Seismic and ABC

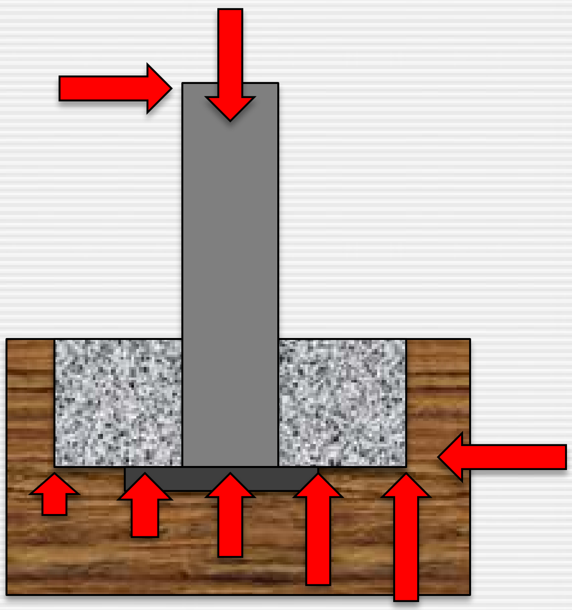


Versatile Connection Types

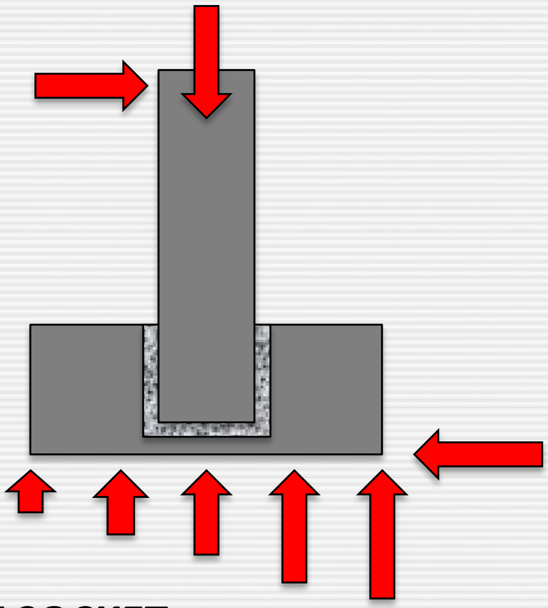
Connections concepts common to many systems:

- Socket connections
- Pocket connections
- Grouted ducts and sleeves
- Mechanical connections

Versatile Connections - Sockets



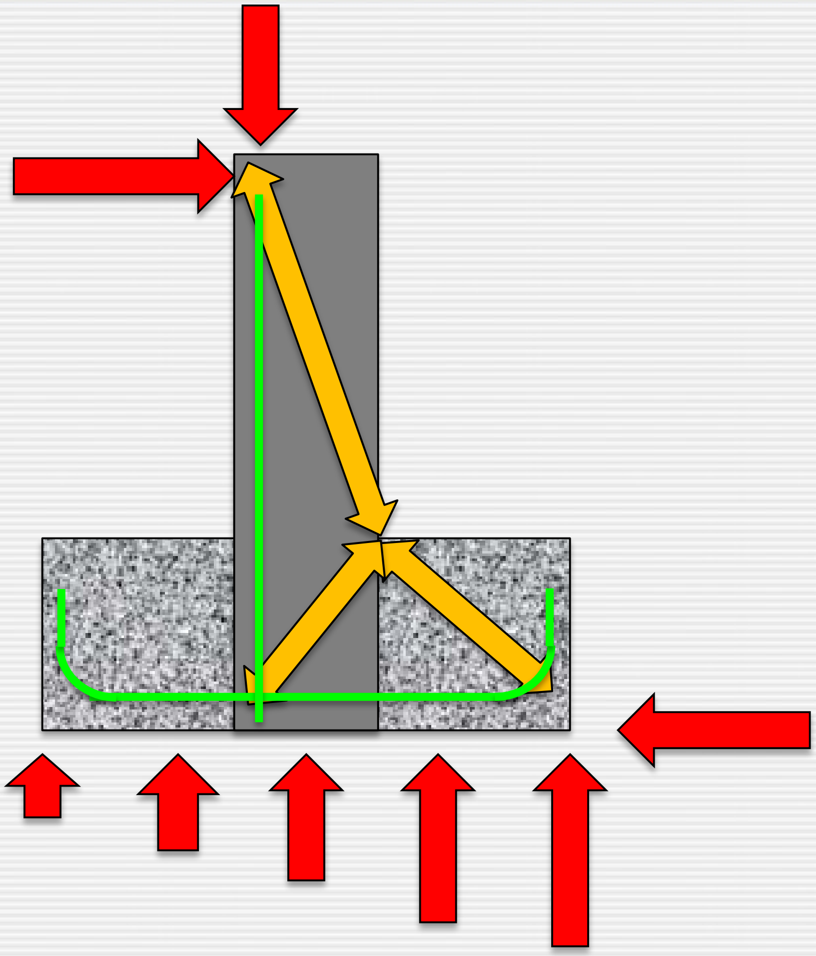
WET SOCKET
Column: PC concrete or CFT
Footing: cip concrete



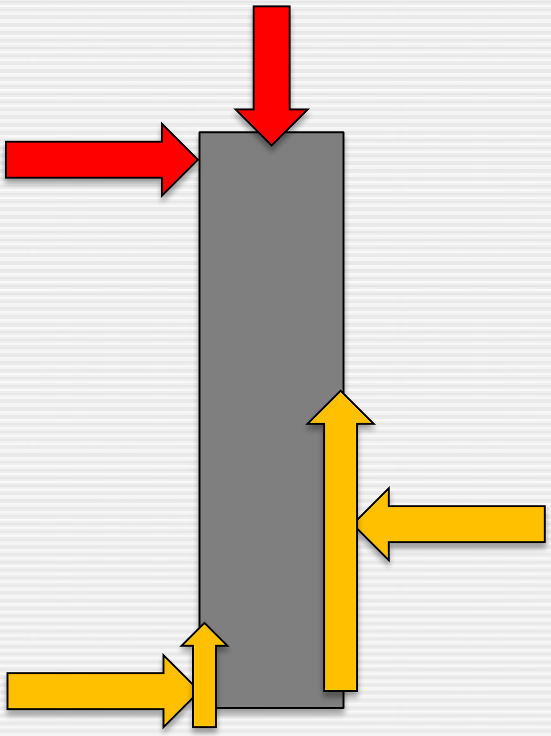
DRY SOCKET
Column: PC concrete or CFT
Footing: PC concrete
Annular space: cip grout or concrete

No steel crosses column-footing interface.
Quick to construct.
Best if $h_{\text{footing}} \geq 1.0\ D_{\text{col}}$
Well suited to footings. Less so for cap beams.

Sockets – Precast Concrete Column



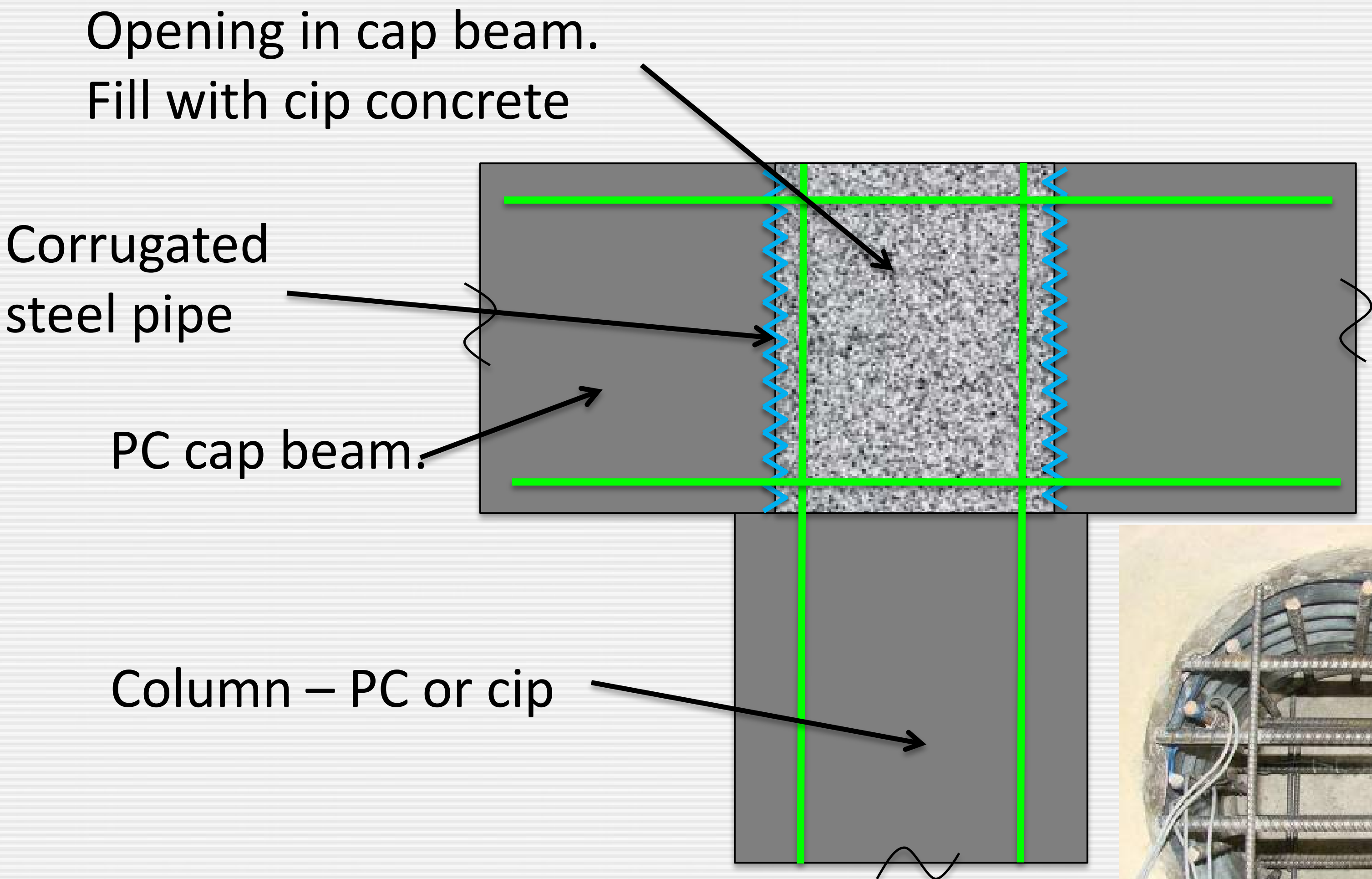
STRUT AND TIE MODEL



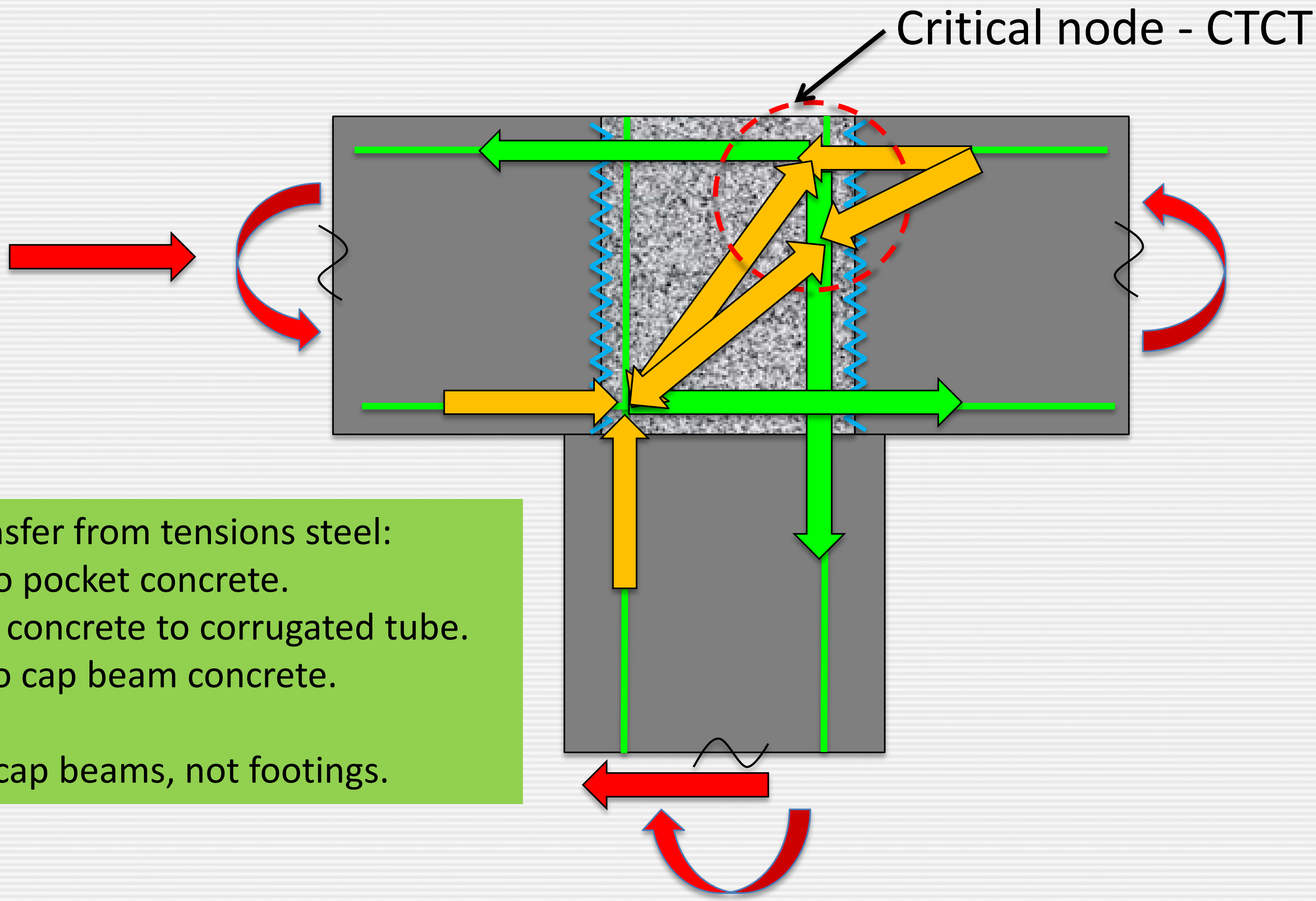
FORCES ON COLUMN

Vertical load can be carried by friction

Pockets – Precast Concrete Cap Beam



Pockets – Precast Concrete Cap Beam

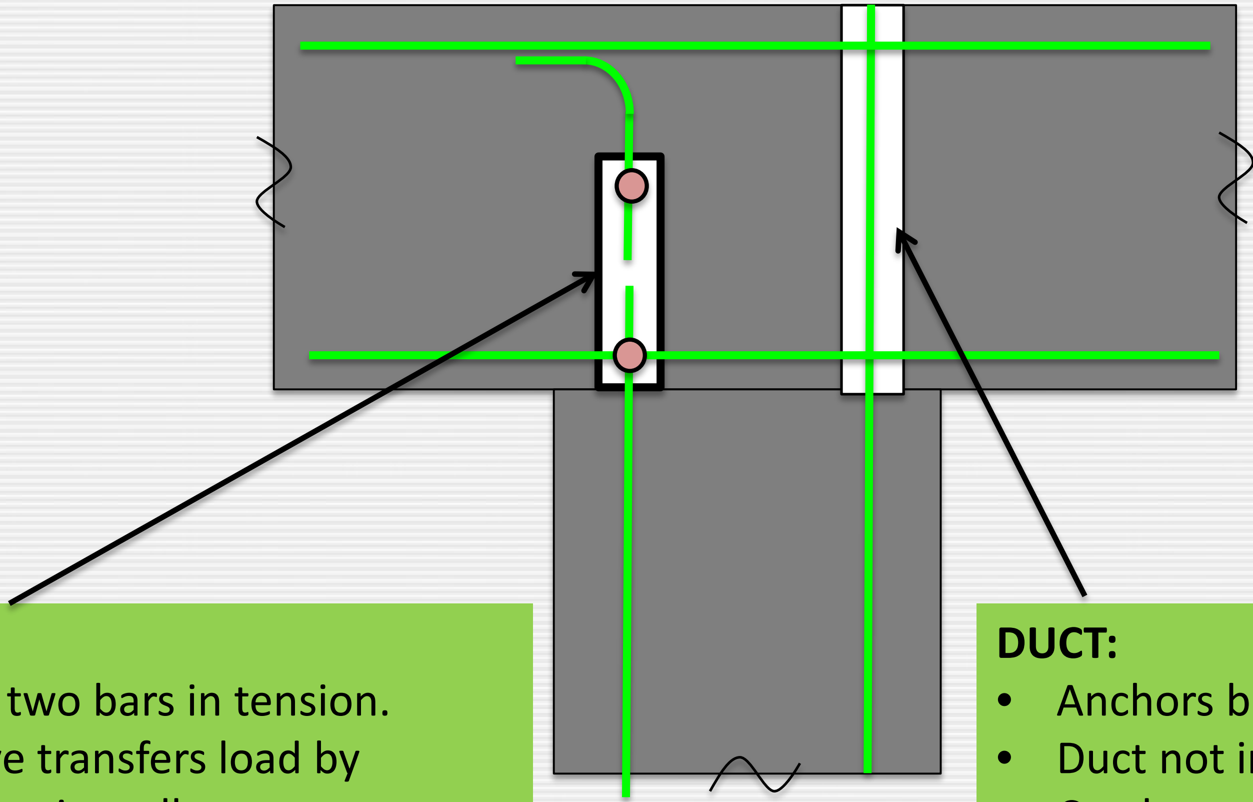


Force transfer from tensions steel:

- Steel to pocket concrete.
- Pocket concrete to corrugated tube.
- Tube to cap beam concrete.

Good for cap beams, not footings.

Grouted sleeves and ducts



SLEEVE:
- Joins two bars in tension.
- Sleeve transfers load by tension in wall.
- Thick walls. Proprietary brands.
- Placement tolerances quite tight.

DUCT:
- Anchors bar in concrete.
- Duct not in axial tension.
- Can lap-splice other bars to outside of duct.
- PT duct – thin wall. Non-proprietary.
- More generous tolerances.

Grouted sleeves and ducts

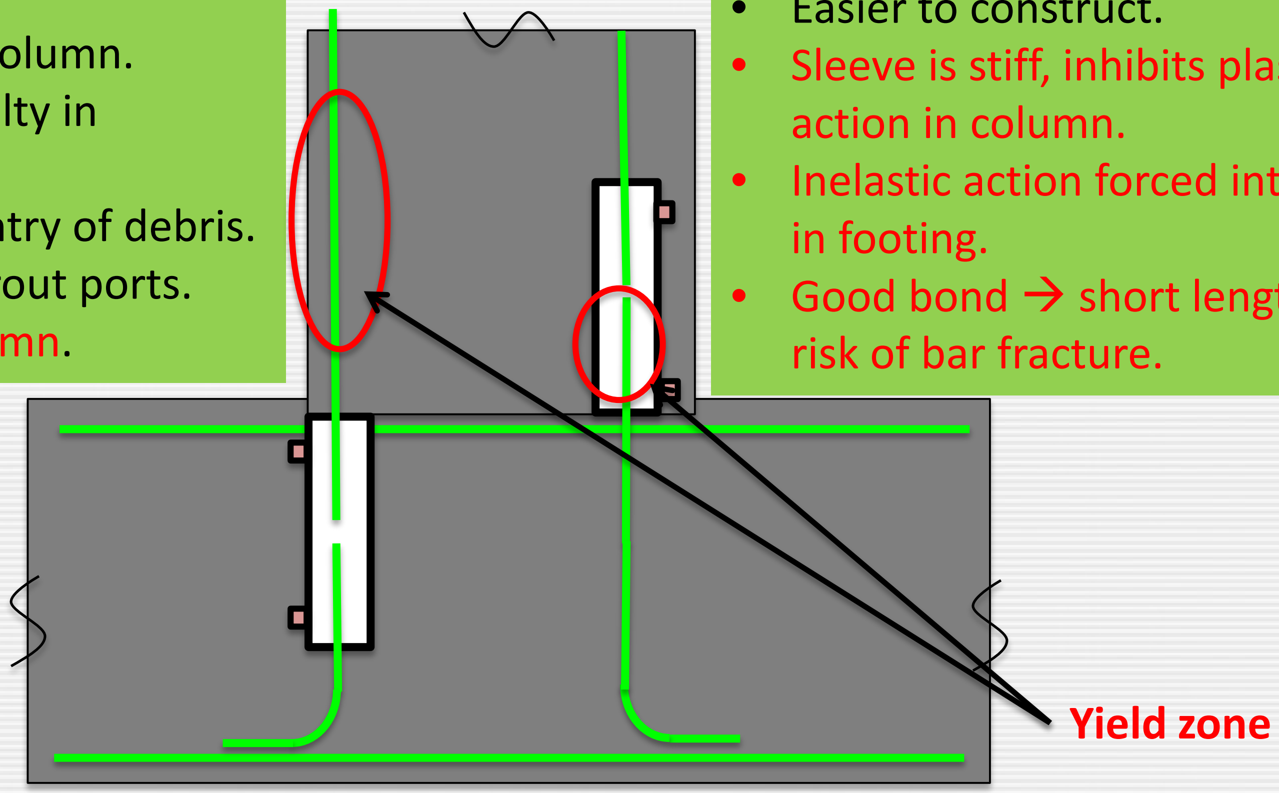
WHERE TO PLACE SLEEVES?
Consider both strength and deformation capacity.

IN FOOTING

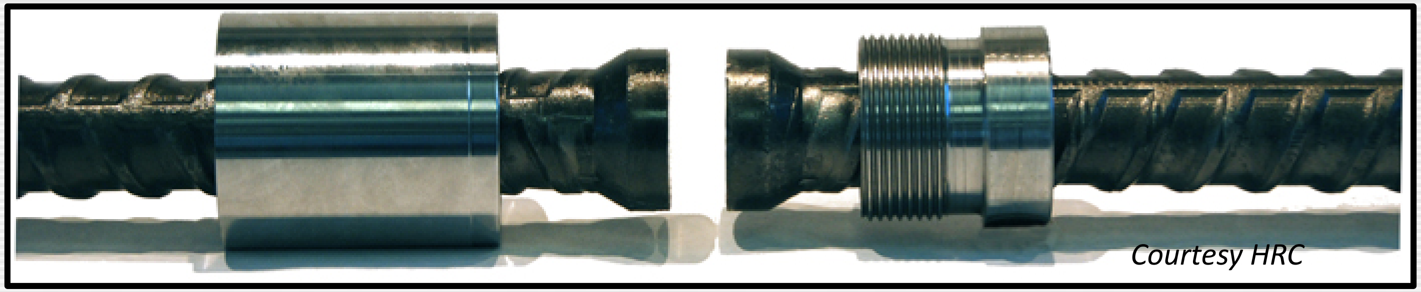
- Bars project from column. Potential for difficulty in transportation.
- Need to prevent entry of debris.
- Harder to access grout ports.
- Yielding in the column.

IN COLUMN

- Easier to construct.
- Sleeve is stiff, inhibits plastic action in column.
- Inelastic action forced into bar in footing.
- Good bond → short length → risk of bar fracture.



Mechanical connectors



MECHANICAL CONNECTORS

Tension butt-splice between bars.

- Shorter than sleeve. Less effect on plastic hinge zone.
- Need careful alignment for screw threads.

Emulative Systems

“Emulation” Goal

- With a precast system, emulate the performance of a traditional c.i.p. system

In most cases,

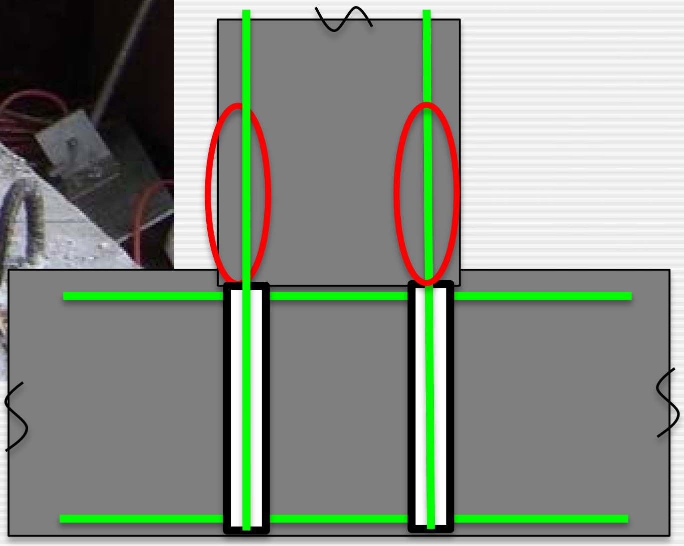
- Connection to be as strong as the column.
- Inelastic action occurs in the column.
- Avoid brittle failure modes (e.g. shear).
- Provide flexural ductility.

Emulative Systems

- Precasting the ***cap beam*** saves the most time, e.g. for:
  - Shoring
  - Formwork
  - Steel fixing
  - Casting-curing cycle

- Precasting the ***column*** saves some time, but:
  - Contractors prefer to cast in place (keeps work in-house).
  - Time savings are less than with cap beam.

Emulative Systems – Grouted Ducts



EMULATIVE SYSTEM

- Precast column with projecting bars
- Ducts in foundation/cap beam.
- All inelastic action in column. Just like c.i.p.

Haraldsson, Stanton, Eberhard

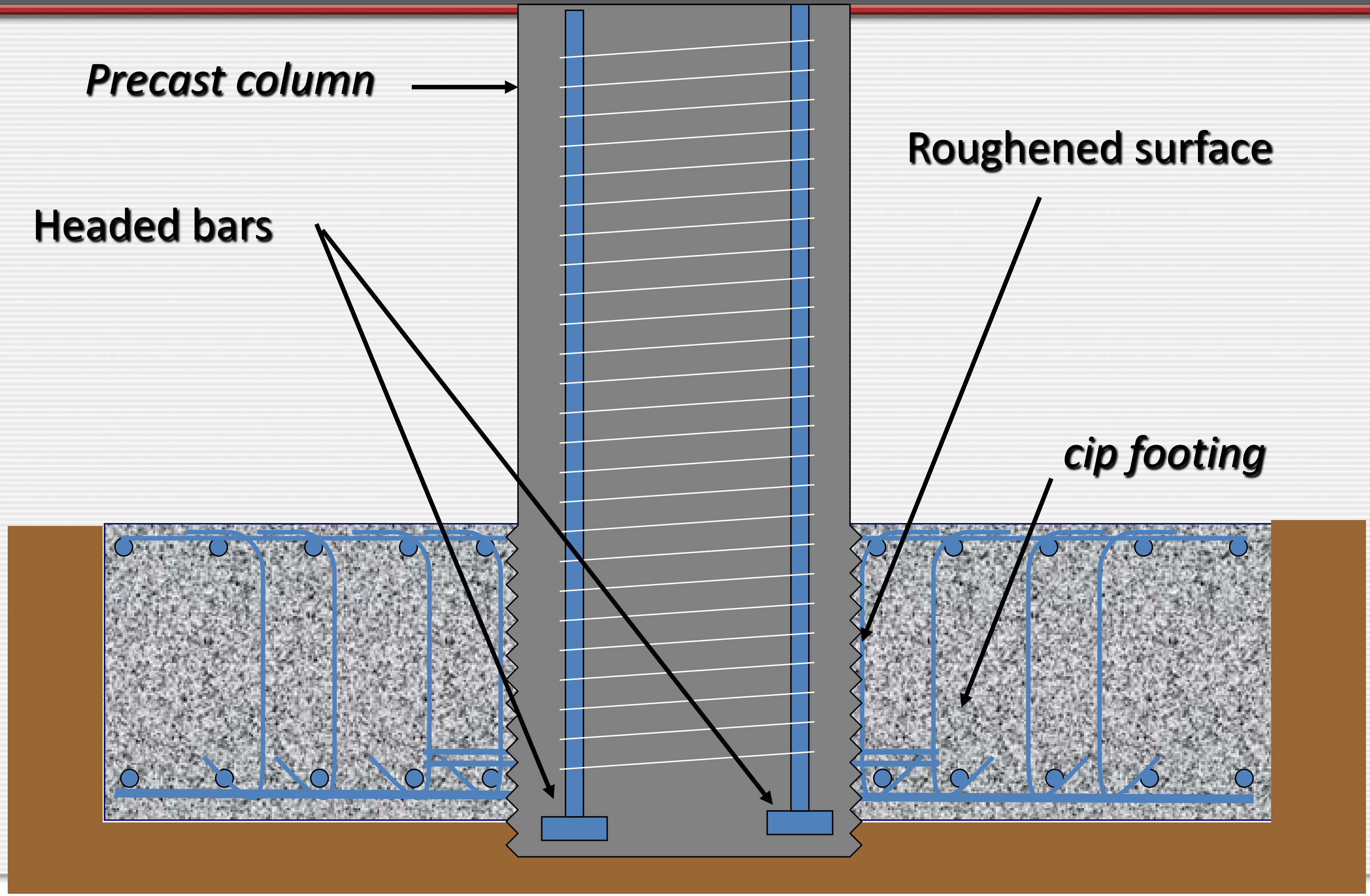
Emulative Systems – Grouted Ducts

Precast cap beam on c.i.p. columns. (Contractor choice to save time).
SR 520, Redmond WA.

First stage cap beam (pc) shown here.

Second stage (i.e. "diaphragm") is cast in place with slab, after girder erection.

Emulative Socket Connection



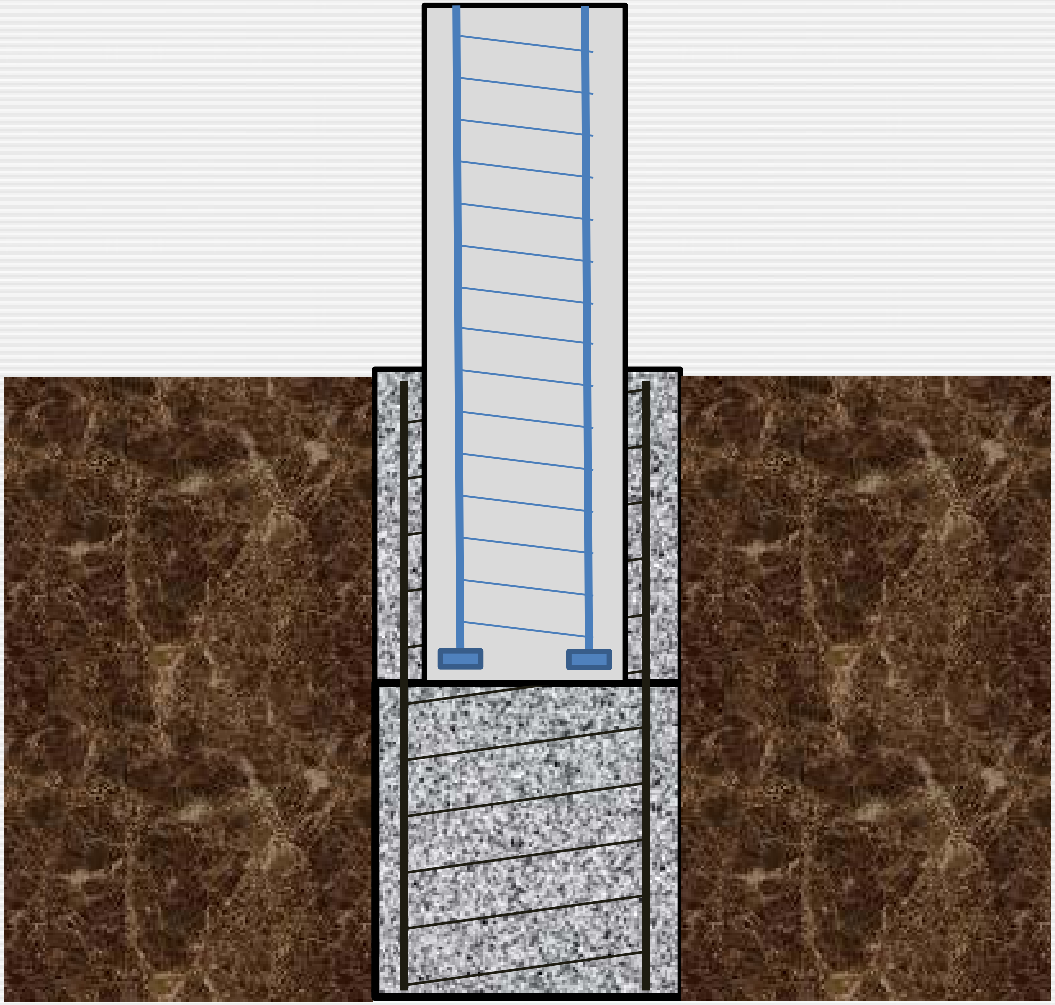
Emulative Socket Connection

Emulative Socket Connection

After seismic testing. All inelastic action in column. Foundation undamaged.

Haraldsson, Stanton, Eberhard

Emulative Drilled-Shaft Connection



Emulative Drilled-Shaft Connection

Strong column / weak shaft

BAD

Strong shaft / weak column

GOOD

Tran, Stanton, Eberhard

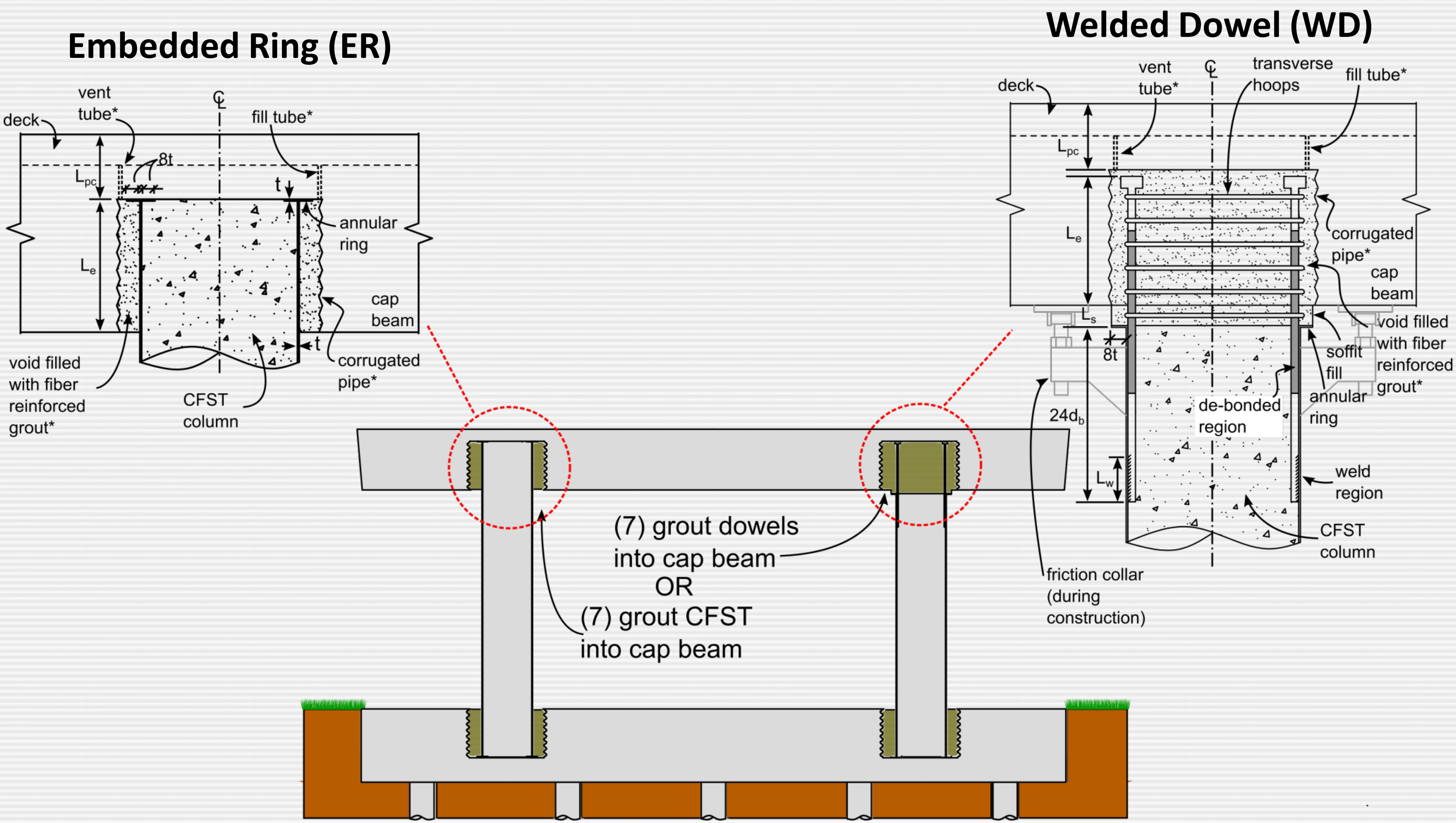
Concrete Filled Tubes (CFTs) for Seismic Resistance

Courtesy
Charles Roeder and Dawn Lehman,
University of Washington

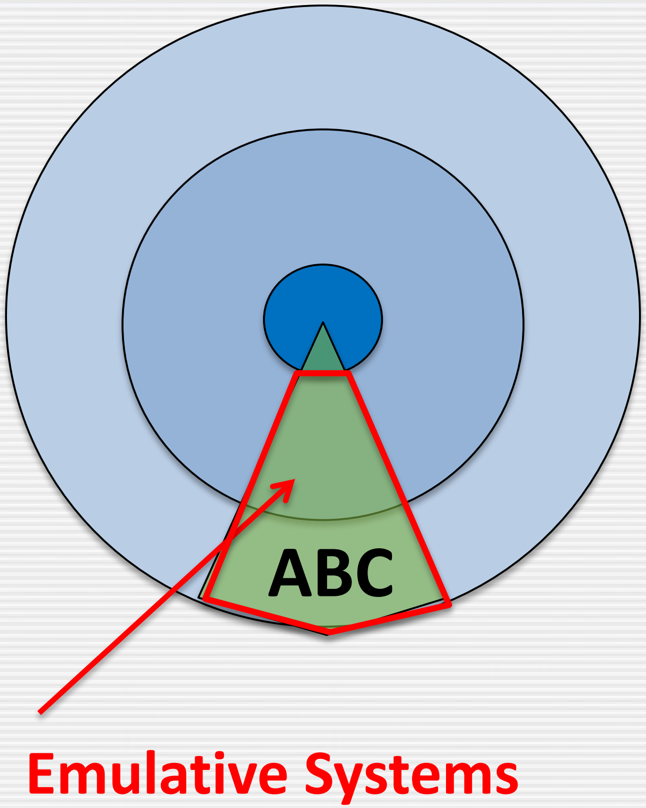
Concrete Filled Tube (CFT)

CFTs can be used as foundation elements (piles, shafts) and piers in elevated bridges

Concrete Filled Tube (CFT)



Emulative Systems - Summary



Connections in Emulative Systems – Summary

- All of the major connection types (Socket, Pocket, Grouted Sleeves or Ducts, Mechanical Connectors, CFTs) have been tested under cyclic loading.
- All can provide sufficient strength.
- Most can provide ductility equal to that of c.i.p. construction.
- ***Performance depends strongly on details.***

Enhanced Seismic Performance

To achieve ***more than Code*** performance
(i.e. more than Life Safety)*:*

Most work on minimizing ***downtime*** and ***damage:***

- Re-centering – "Zero residual drift"– no bridge closure.
- Minimizing damage to columns – minimal repair costs.
- Combinations of the two.

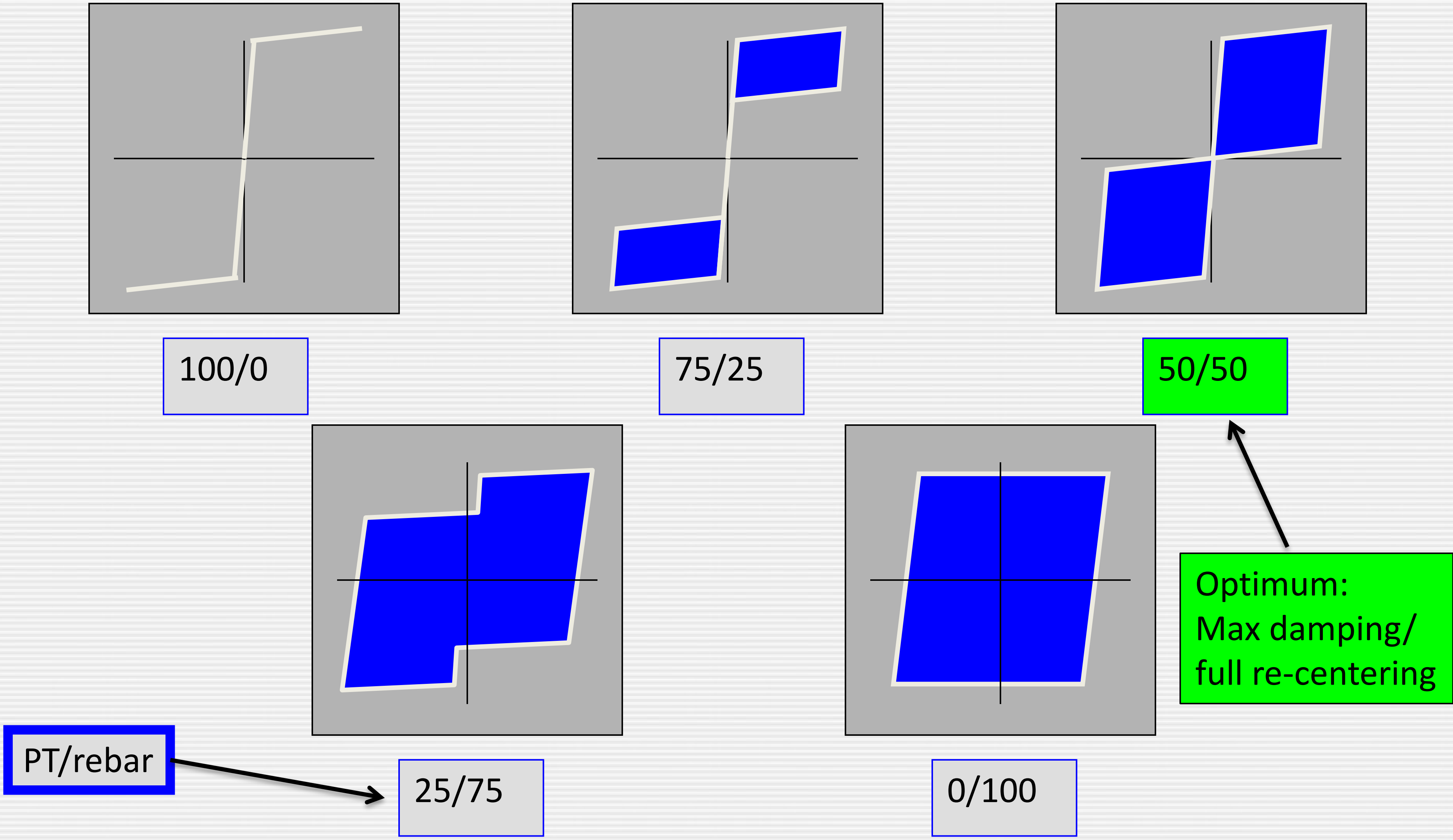
Re-centering can be achieved by:

- Unbonded prestressing.
- Shape Memory Alloy (SMA) reinforcement.

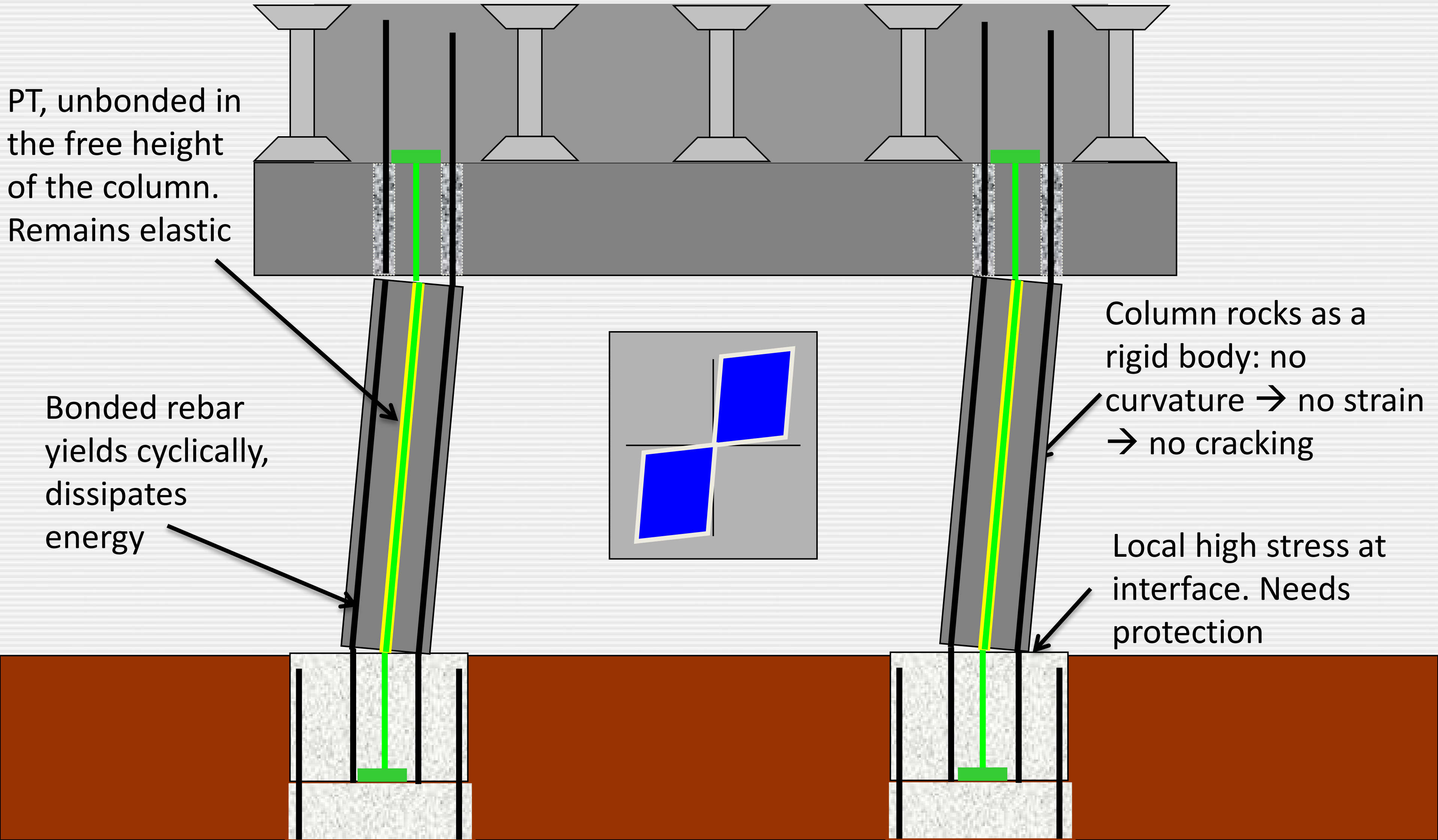
RE-CENTERING SYSTEMS

Unbonded Post-tensioning: Two bees………

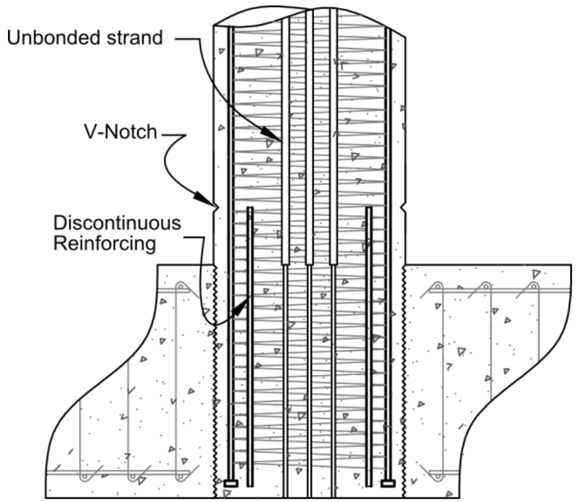
Re-centering System Hysteresis Loops

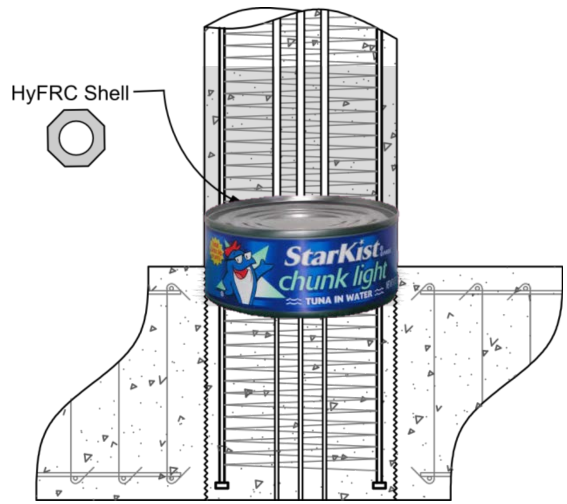


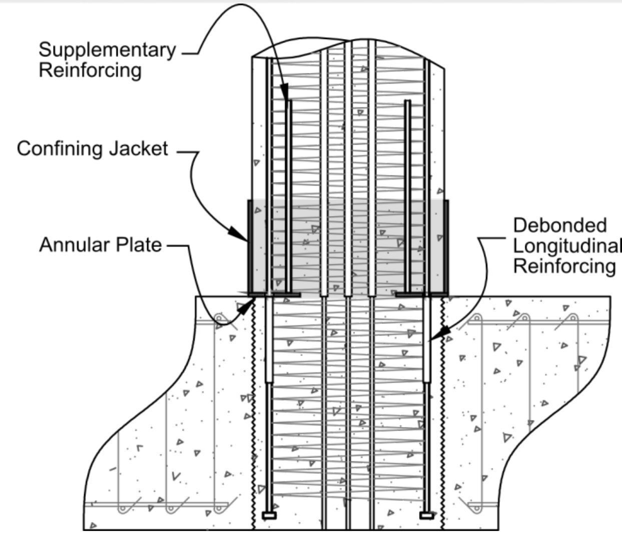
Generic Unbonded PT Bent



Unbonded PT (Rocking) Systems - End Protection



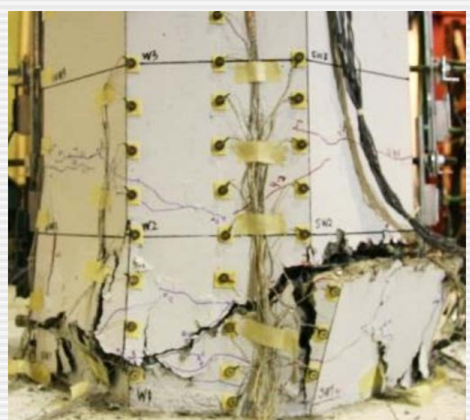




Conventional concrete only

Hybrid Fiber-Reinforced Concrete (HyFRC)

Steel tube confinement



Unbonded PT (Rocking) Systems - Variations

cip column
- ABC???

pc column
- Lifting weight.
- GCs prefer not.

Shell column
- Light weight.
- Need int. and ext. steel shells.
- PT corrosion?

Post-tensioning:
- cip or pc column.
- Site operation.
- Anchorage.
- Potential for corrosion.

Column	cip	pc	shell
Post-T	X	X	X
Pre-T		X	

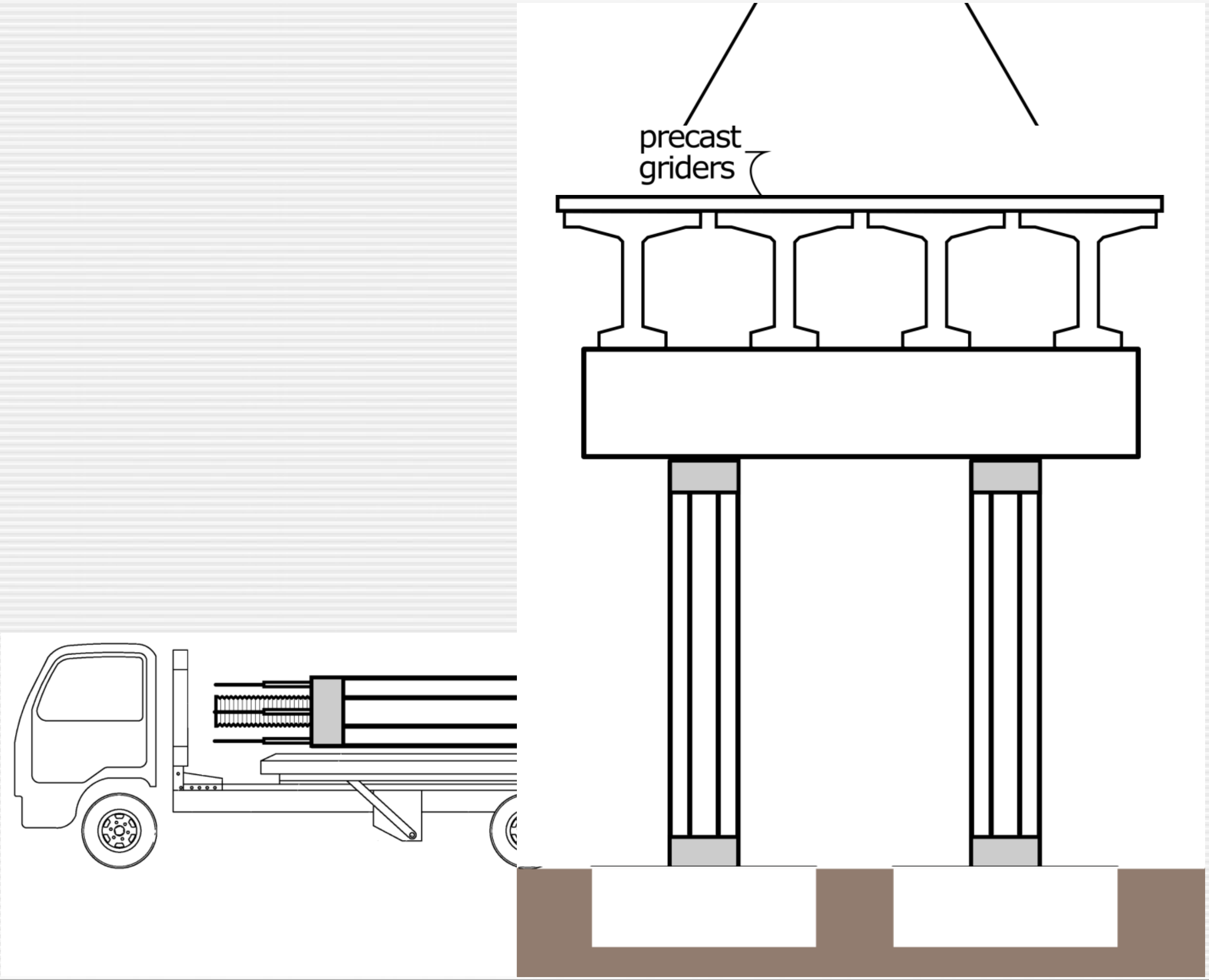
Pre-tensioning:
- pc column only.
- Plant prestressing.
- No anchorages, no corrosion.
- Relies on bond.

Pre-T Precast System.
(Low damage, re-centering)

Thonstad, Stanton, Eberhard
University of Washington

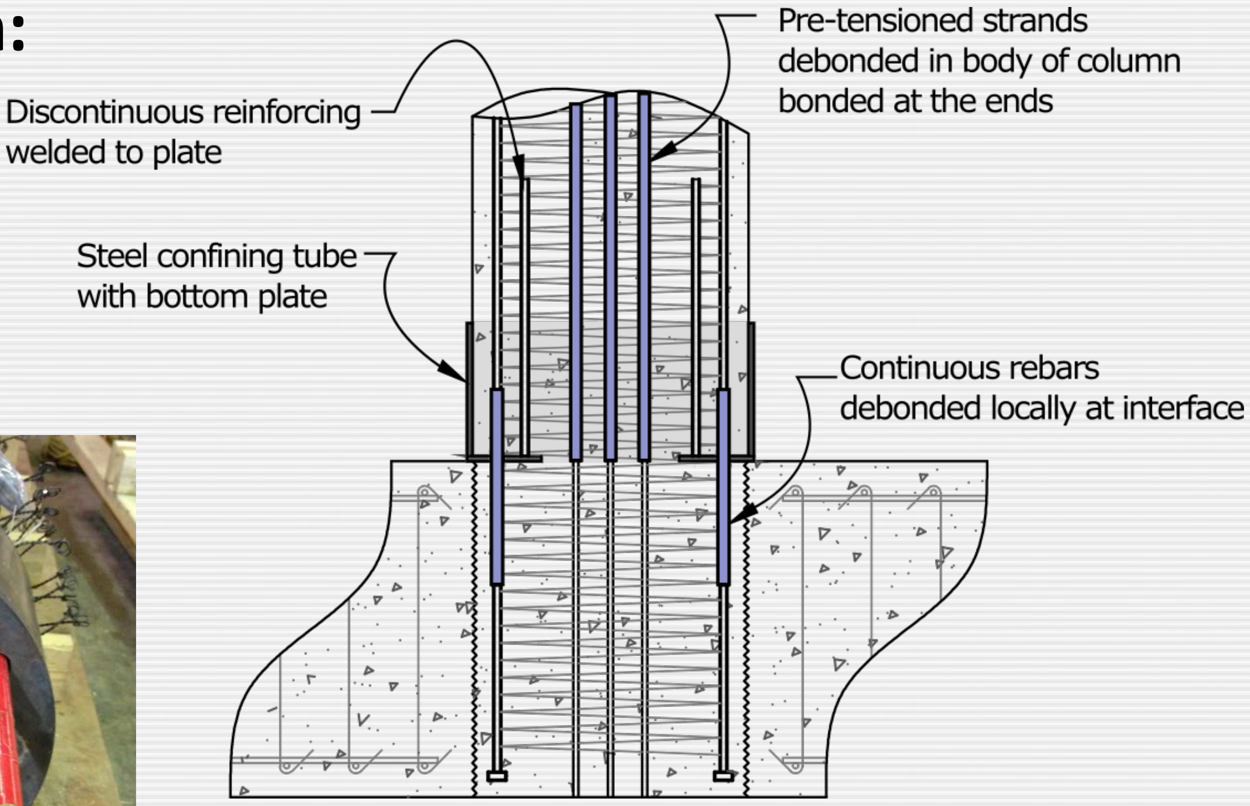
Pre-T Precast System

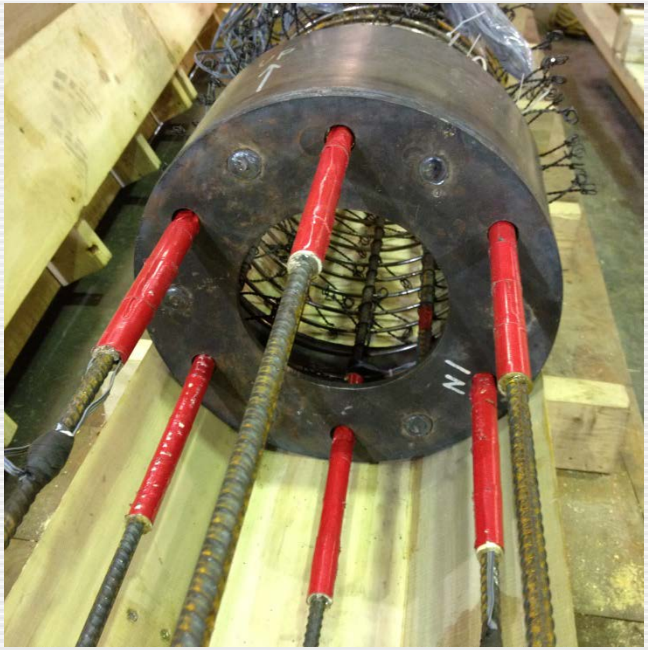
Construction sequence



Pre-T Precast system

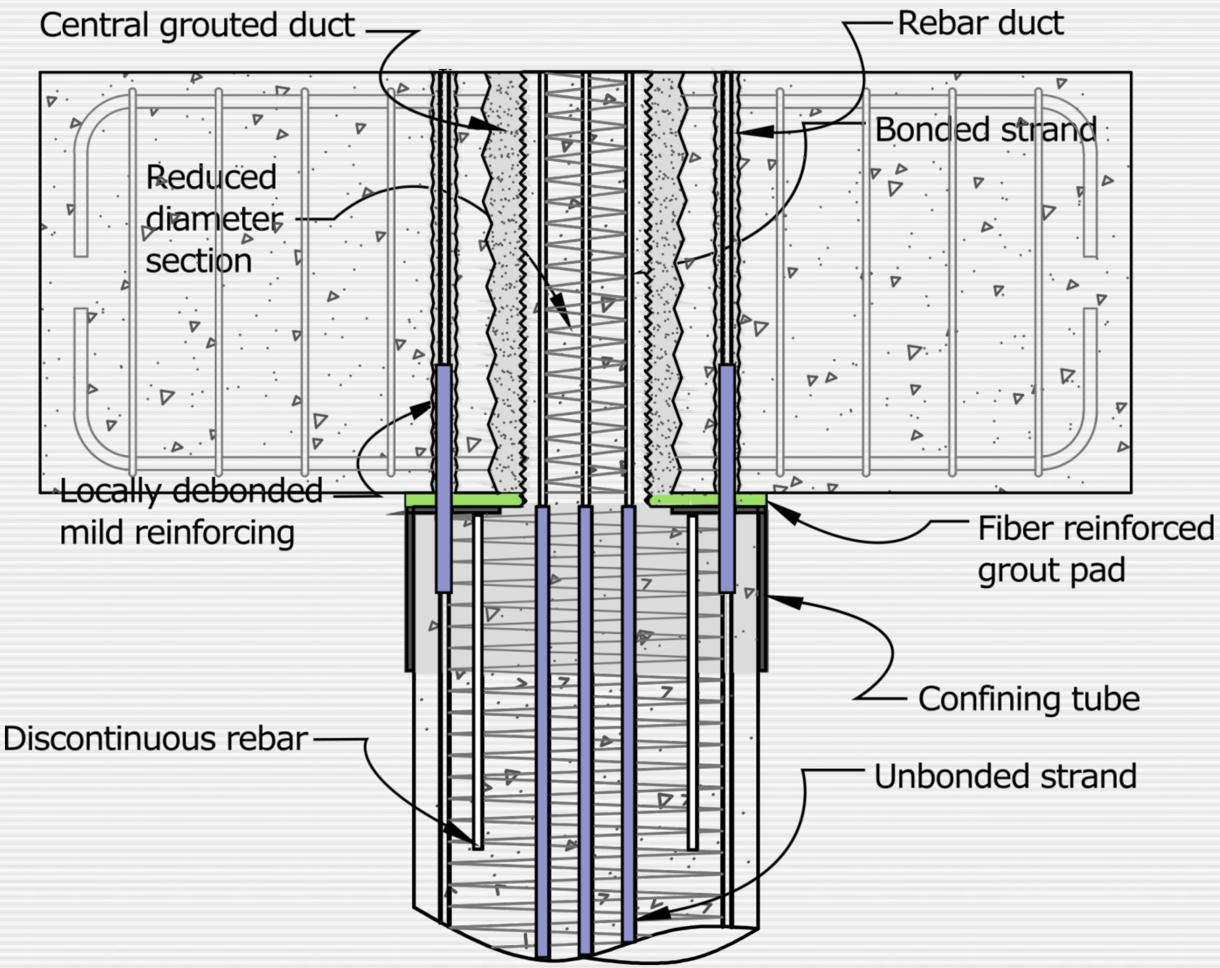
Footing Connection:
Wet Socket





Pre-T Precast system

Cap Beam Connection: Dry Socket & Grouted Duct.



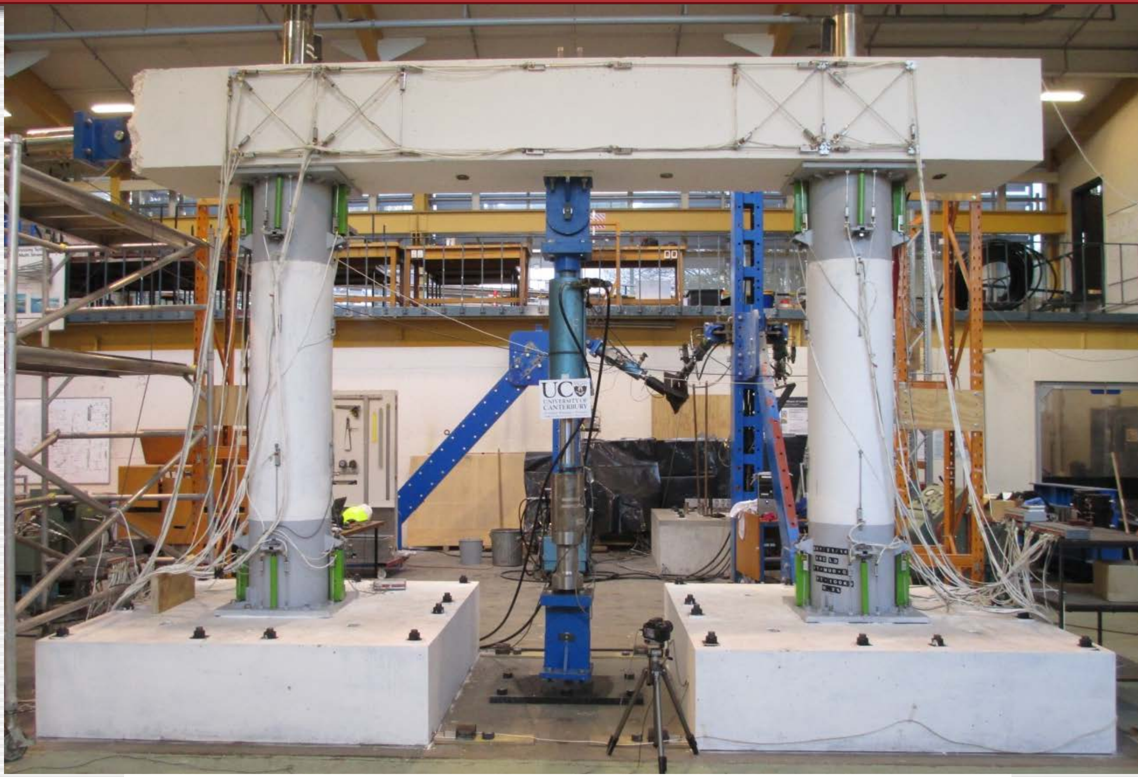
Pre-T Precast system

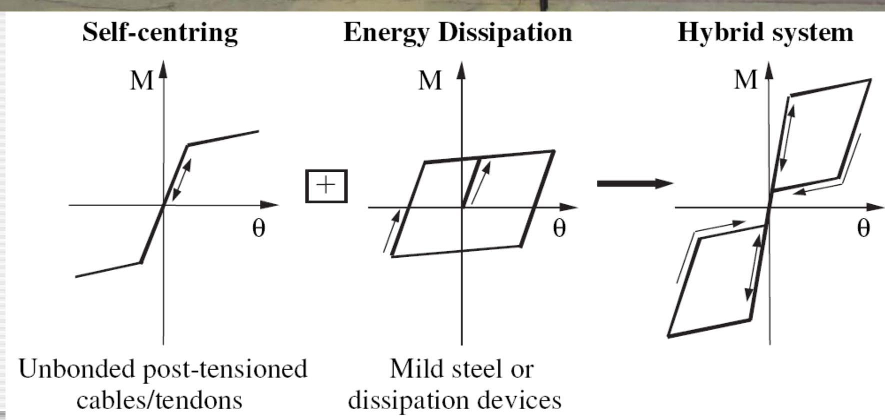
Shaking Table Test: 1995 Kobe /Takatori (PGA = 0.8g)

Low damage Unbonded Post-tensioned Connections with External Dissipaters.

Courtesy Allessandro Palermo,
University of Christchurch, NZ

Unbonded Post-T: External Dissipaters





Low Damage Connections

Unbonded Post-T: External Dissipators

Field Implementation - Wigram Magdala Bridge: detail of dissipater assembly

Unbonded Post-T: External Dissipators

Installing Dissipater Connections

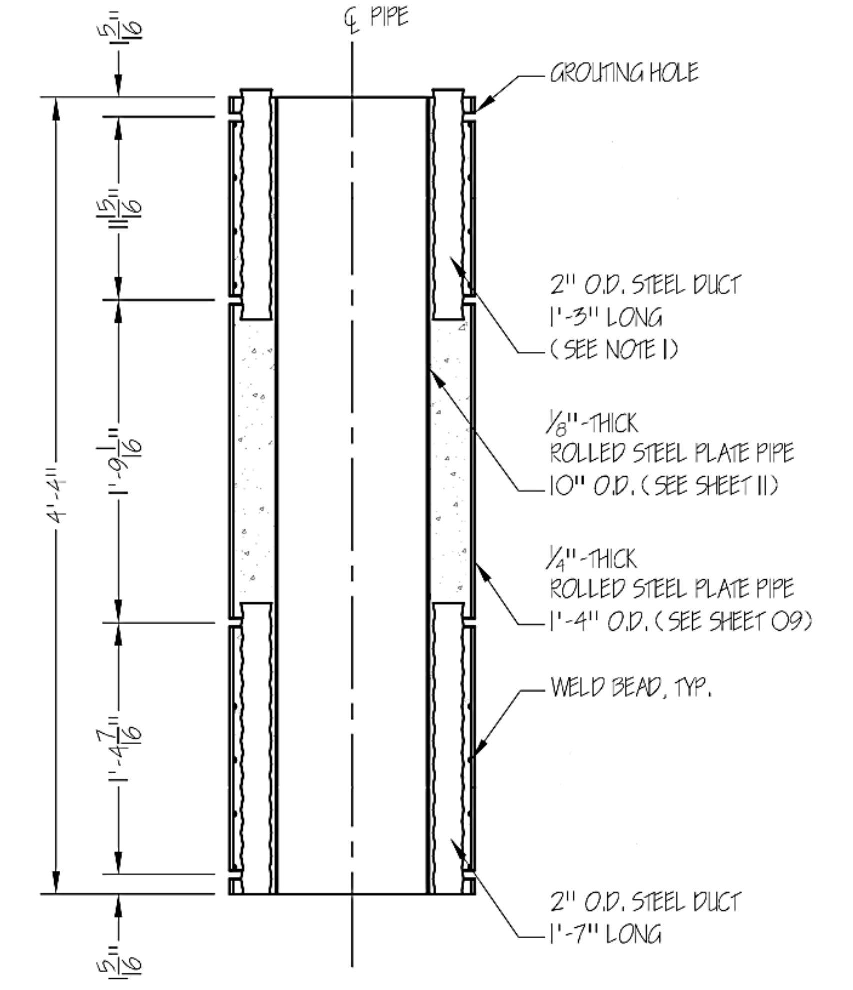
Unbonded Post-T: External Dissipators

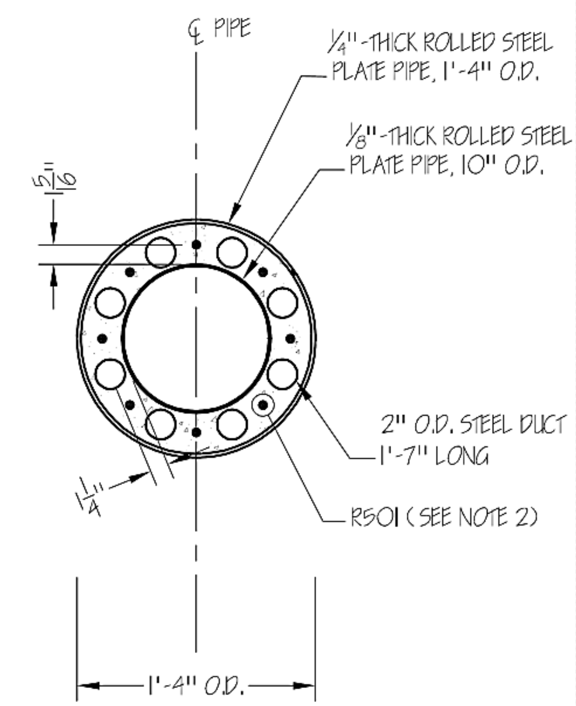
After installation

Low damage Unbonded Post-tensioned Dual Shell Columns.

Courtesy Jose Restrepo,
University of California San Diego

Unbonded PT Dual-Shell Column





44

Unbonded PT Dual-Shell Column

Concentric Steel Shells

- Hollow-core composite section
- No need for formwork or rebars

Post-Tensioning System

- PT bar and polyurethane bearing in series.
- Prevents PT bar from yielding.

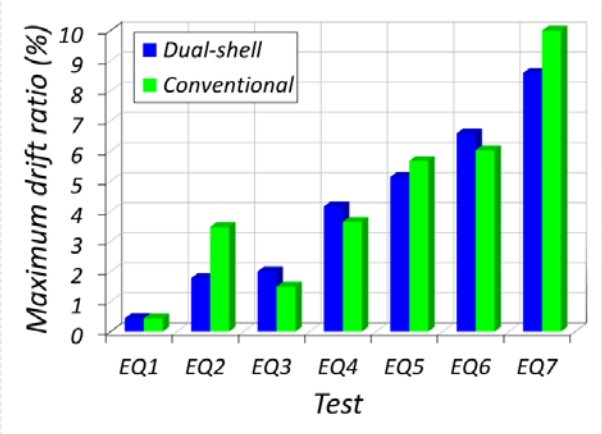
INTERNAL Energy Dissipators

- Unbonded stainless-steel dowels
- Grouted into column ducts
- Circumferential welds inside outer shell

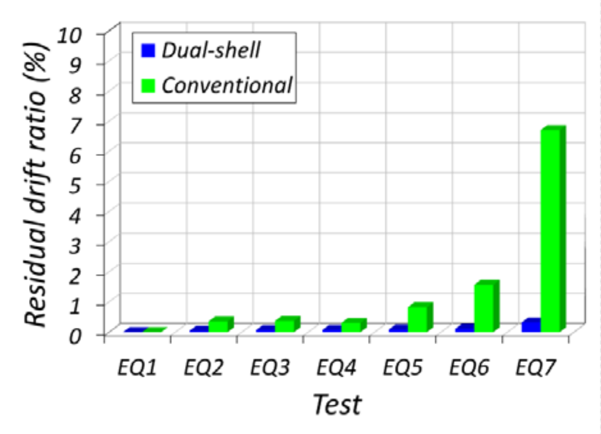
EXTERNAL Energy Dissipators

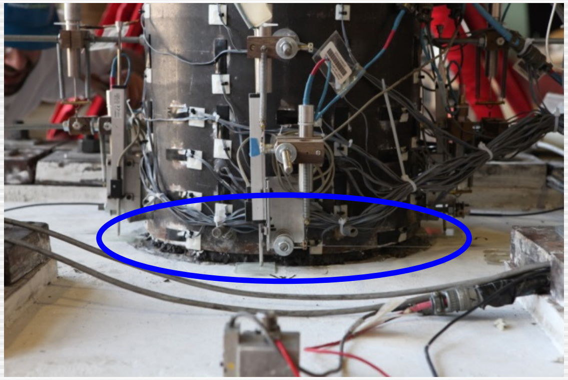
- Buckling-restrained hysteretic devices
- Connected to outer shell and footing
- Allow rotation at connections

Unbonded PT Dual-Shell Column



Drift-Ratio Response





Observed Damage

Self-centering dual-shell column:

- Damage limited to the interface region.
- Mortar crushing, 1-in. (25-mm) deep.
- Energy dissipater fracture.

Conventional RC column:

- Damage up to 2 diameters above base.
- Extensive concrete cover spalling.
- Longitudinal rebar fracture.

Enhanced Seismic - Summary

Efforts to limit:

- *Residual drift*
- *Damage*

Methods:

- *Unbonded Prestressing, rocking*. Several shown.
- *SMA bars/ECC, bending*. Not shown. See Saiidi.

Open questions:

- *System complexity*. Pre-fabricate as much as possible.
- *Post-EQ repair?* Choice: Internal or external dissipators.

Build-your-own Solution

- Many new concepts have been developed.
- All those shown have been tested.
- Details are critical (as always!)
- Can mix and match to suit any particular application. But first be sure that the concept is clear.

If you do not know how the structure should behave, it does not know either.

Build-your-own Solution

An other
Bridge
Concept

Thank You!

Questions ?

Mechanical Splices (Couplers) in and Adjacent to Plastic Hinge Regions and their Impact on Plastic Deformation Capacity of Bridge Columns

M. Saiid Saiidi

http://wolfweb.unr.edu/homepage/saiidi/

Professor, Department of Civil and Environmental Engineering

Director, Center for Advanced Technology in Bridges and Infrastructure

University of Nevada, Reno, USA

Couplers: Current US Code for Moderate and High Seismic Zones

Code	Coupler Type	Plastic Hinge
AASHTO	Full Mech. Connection	No
Caltrans	Service	No
	Ultimate	No
ACI	Type 1	No
	Type 2	Yes

Unofficial reason for not allowing couplers in PH:

- Insufficient data on columns representing US practice

Topics

1. Couplers and Novel Materials in Earthquake Design
2. Couplers for Accelerated Bridge Construction
3. Couplers in Design for Deconstruction

1- Couplers and Novel Materials in Earthquake Design

- **Performance during earthquake**
- **Serviceability after earthquake**

New

Target performance during earthquake: No Collapse

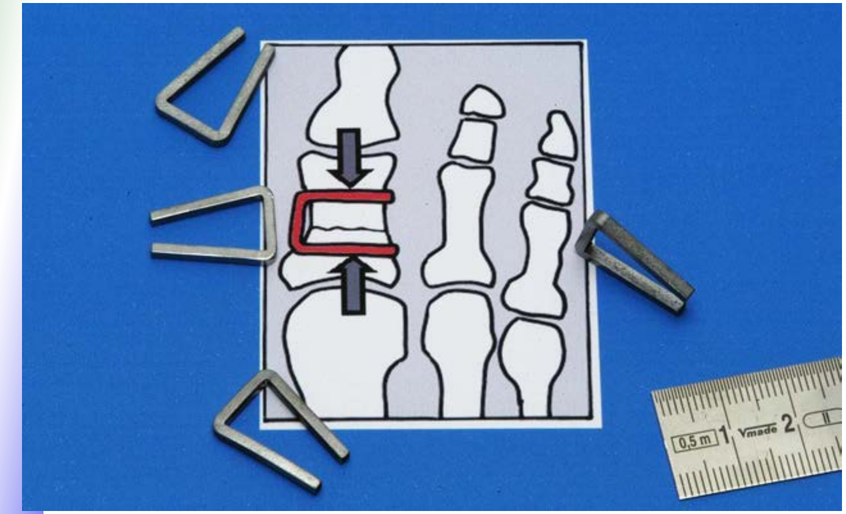
NG

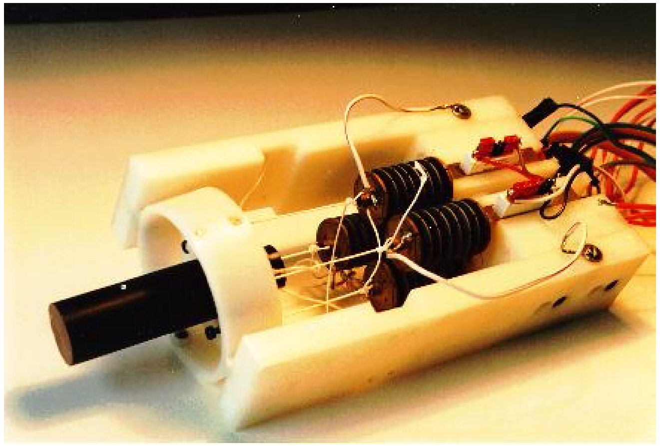
OK

- Serviceability after earthquake:

  Minimize **permanent drift** and **damage**

SMA (Nickel Titanium)

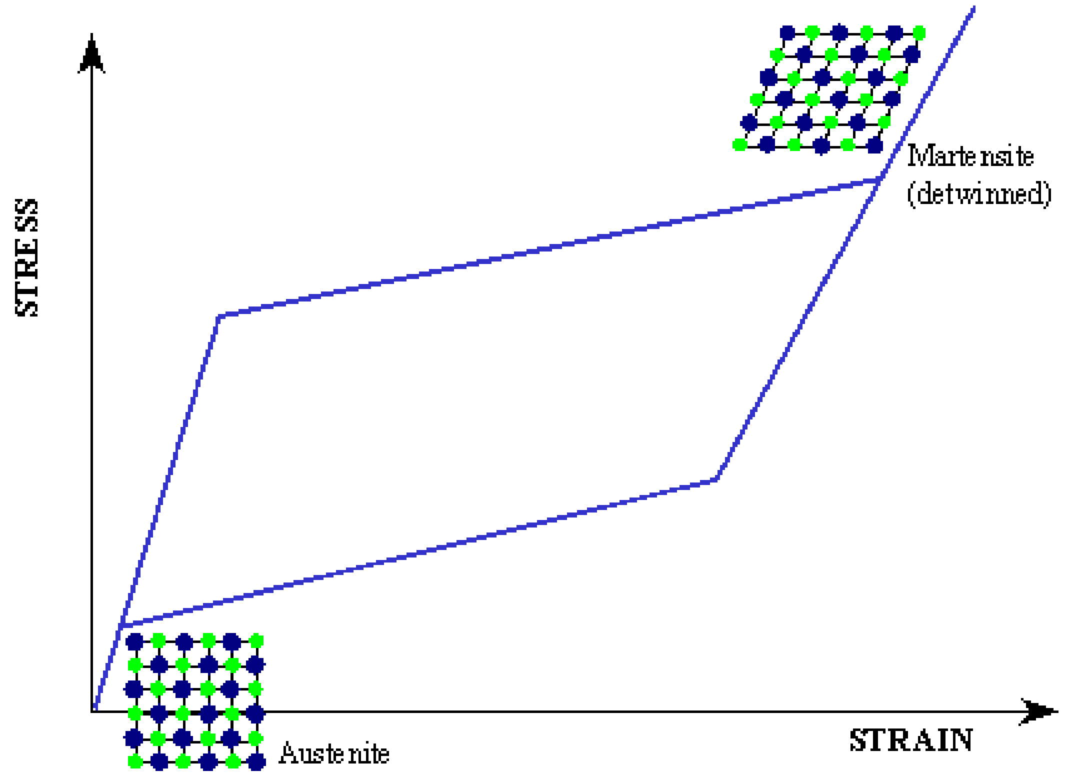




Also military applications

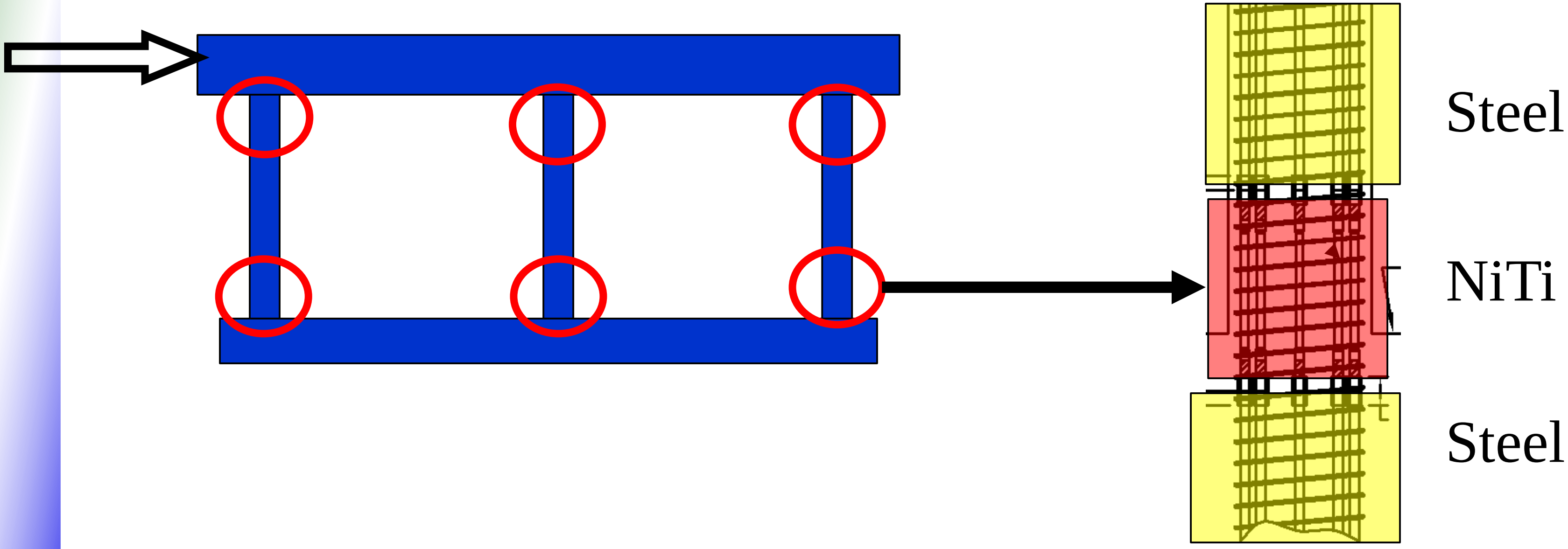
Shape Memory Alloy

- Superelastic response
- Shape memory effects
- NiTi SMA developed in1962
- Cu-Al-Mn SMA being developed



SMA Bar Application

- Very expensive! Approx. 90 x steel cost
- Limit its use only in plastic hinges

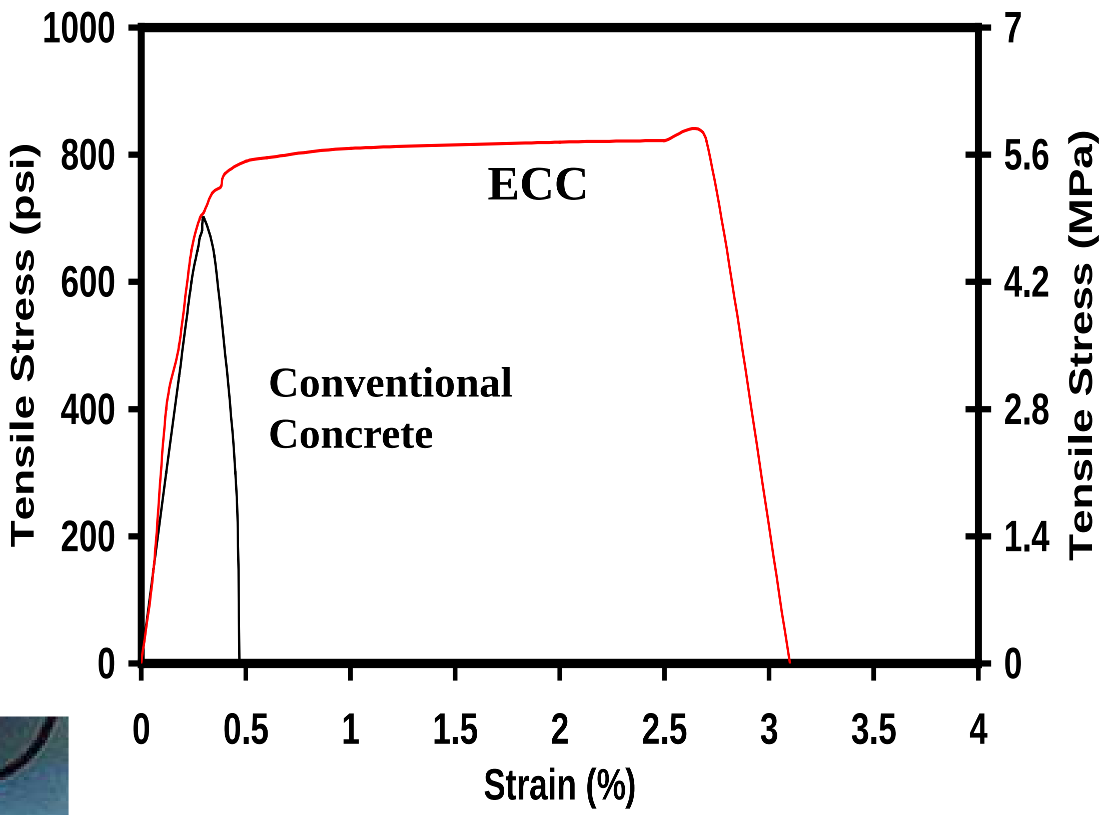


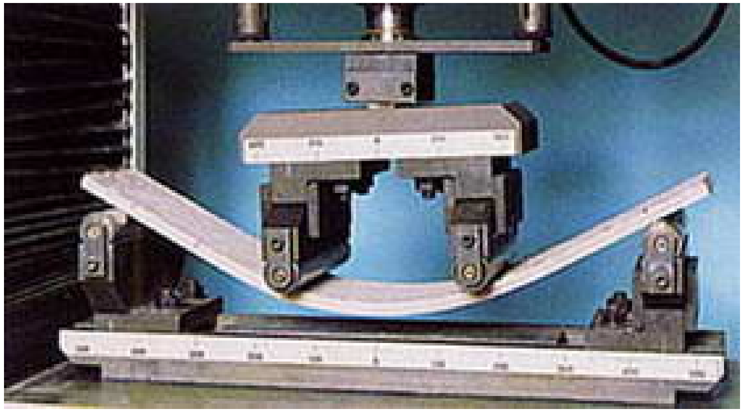
NiTi Bar Sizes and Connections

- Can be made up to 100-mm diameter
- UNR: 13-mm, 16-mm-, and 30-mm bars
- UNR: Threaded couplers; lock screw couplers; headed couplers

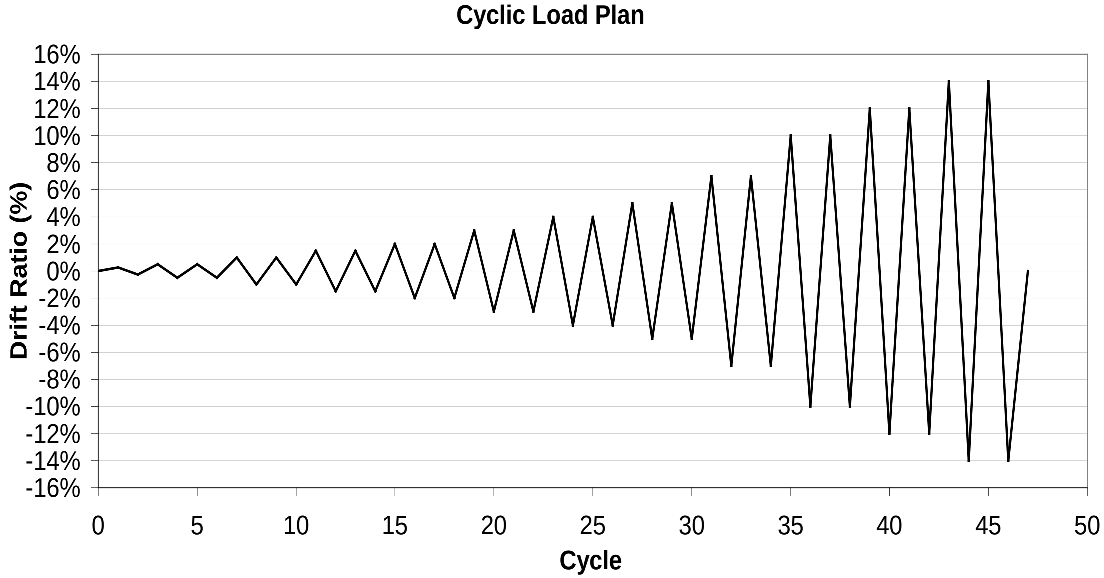
Combining SMA Bars with Engineered Cementitious Composites (ECC, Ductile Concrete)

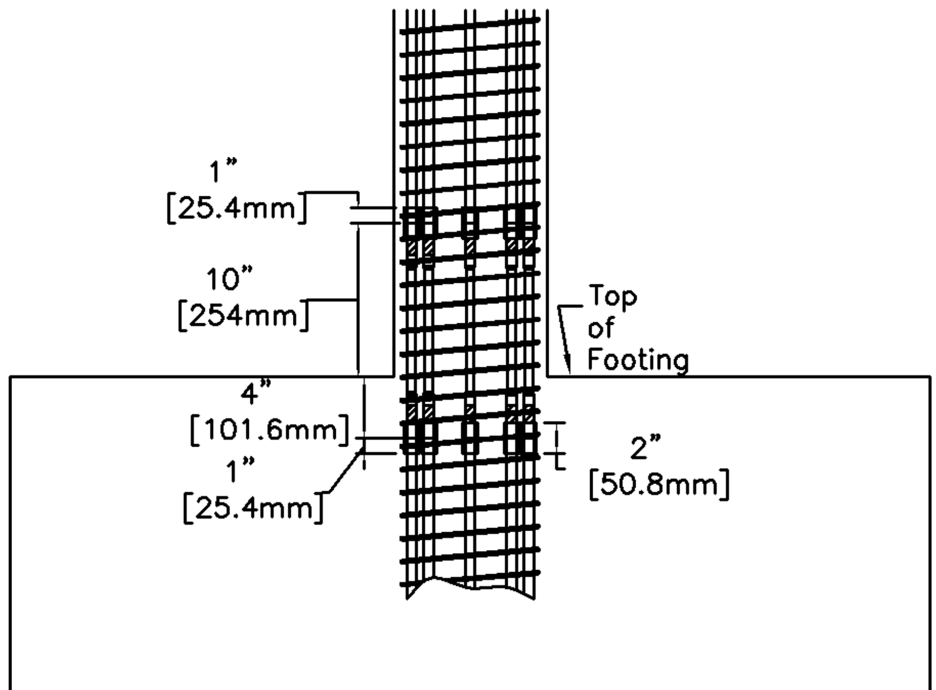
Polyvinyl Alcohol Fiber



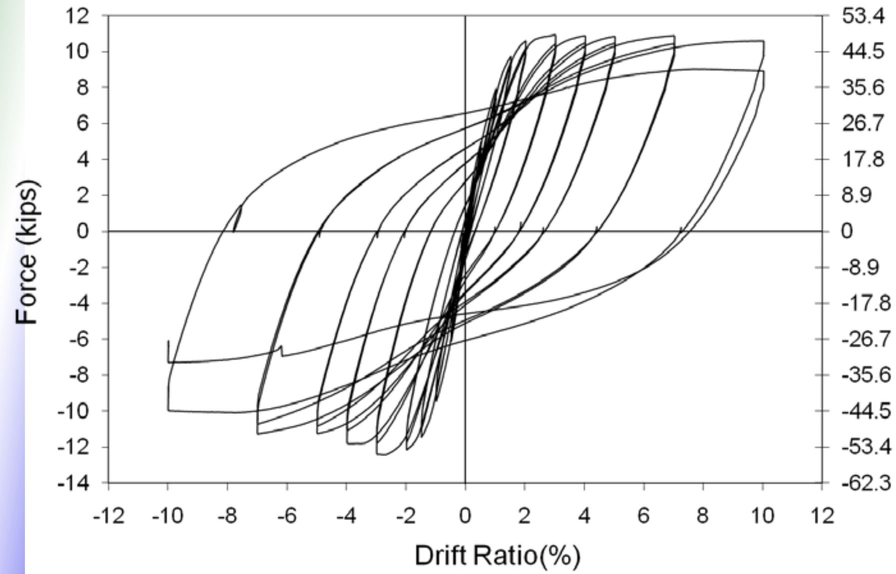



RNC
RNC

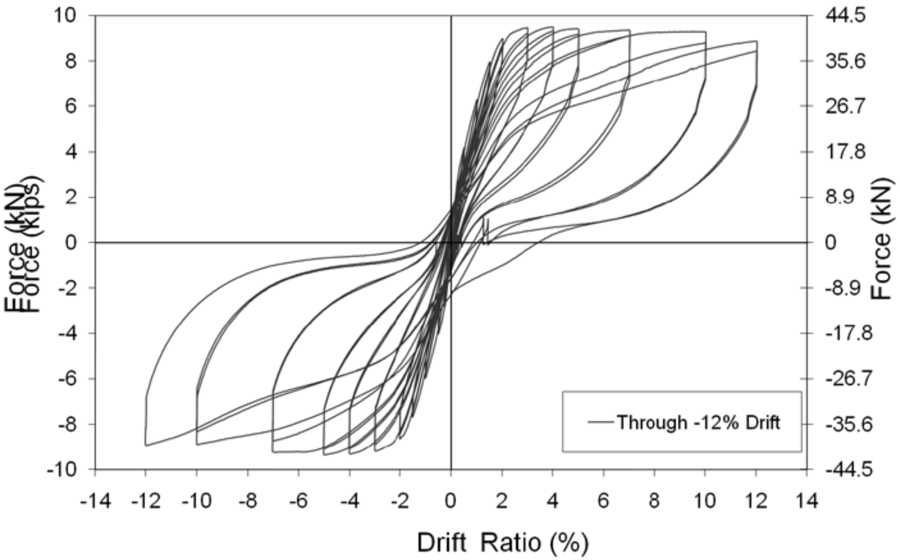

Cyclic Load Plan
Drift Ratio (%)
16%
14%
12%
10%
8%
6%
4%
2%
0%
-2%
-4%
-6%
-8%
-10%
-12%
-14%
-16%
0
5
10
15
20
25
30
35
40
45
50
Cycle


1"
[25.4mm]
10"
[254mm]
Top of Footing
4"
[101.6mm]
1"
[25.4mm]
2"
[50.8mm]

Conventional



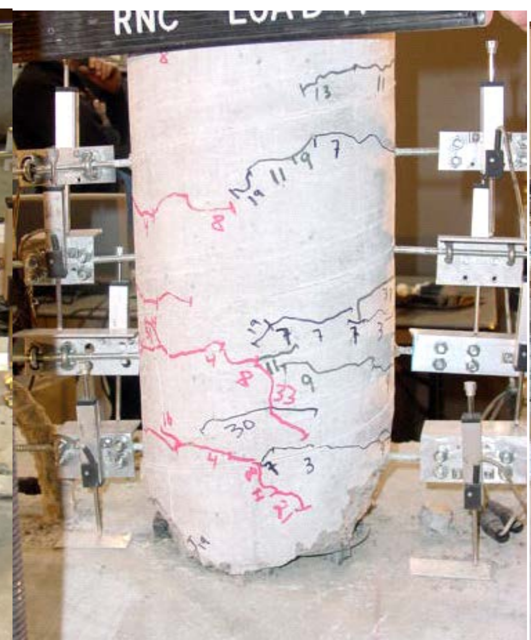
SMA/ECC

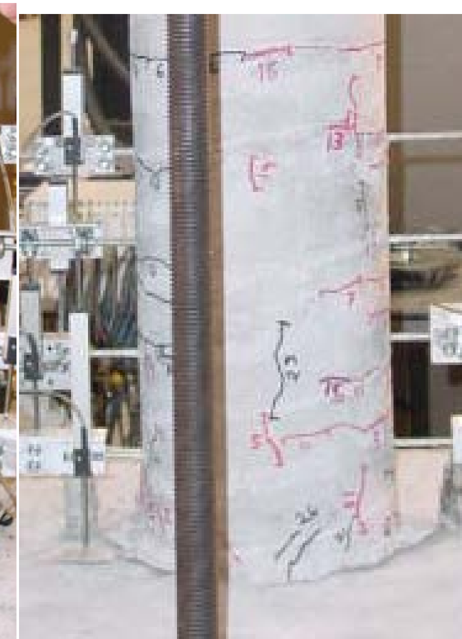


10% Drift

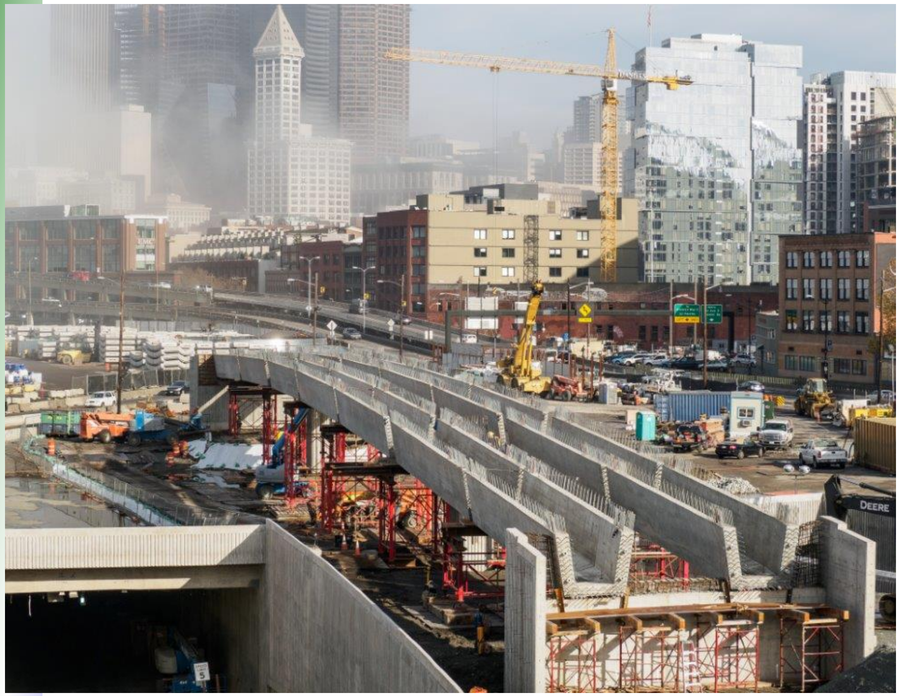
Conventional **SMA/Conc.** **SMA/ECC**

Residual After 10% Drift

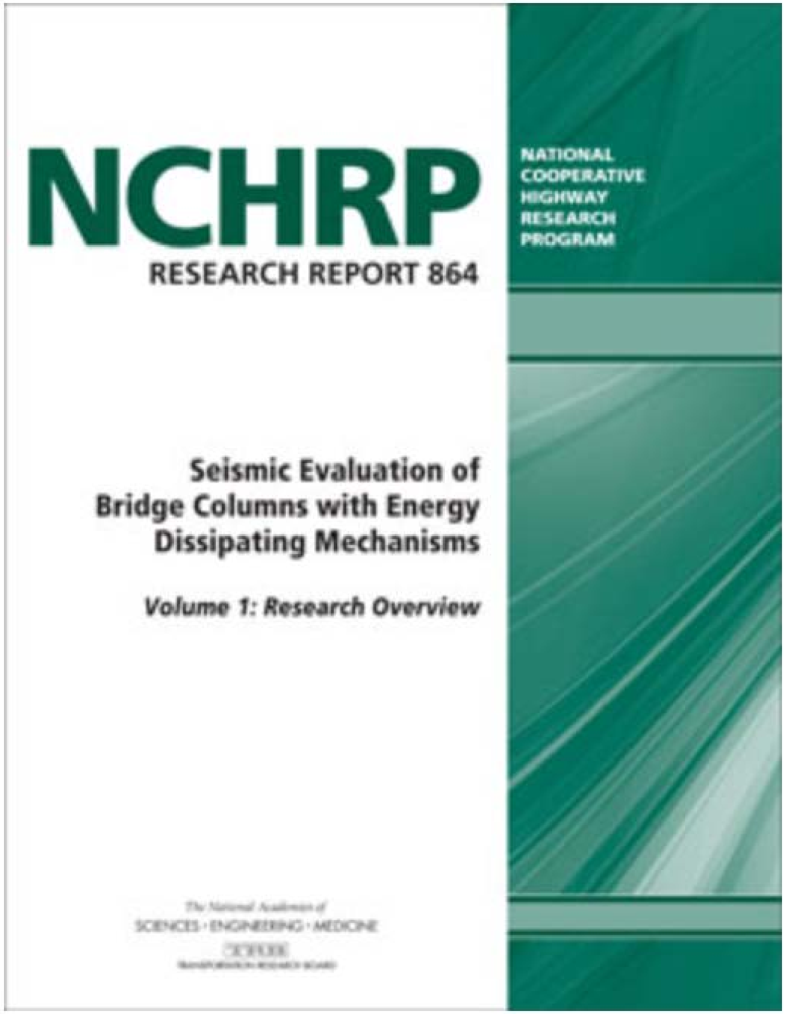




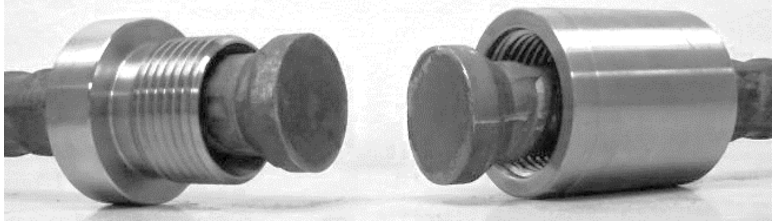
HRC Couplers in Seattle Alaska Way Viaduct- CIP


DEERE

Design Guidelines for SMA Columns



Topic 2 - Couplers for Accelerated Bridge Construction



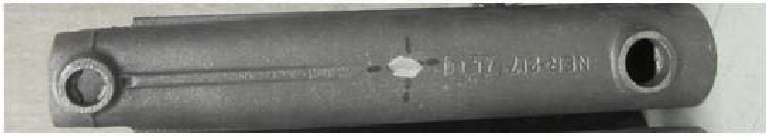
Headed Bar Coupler

[hrc-usa.com]

[erico.com]

[armaturis.com]

Threaded Bar Coupler

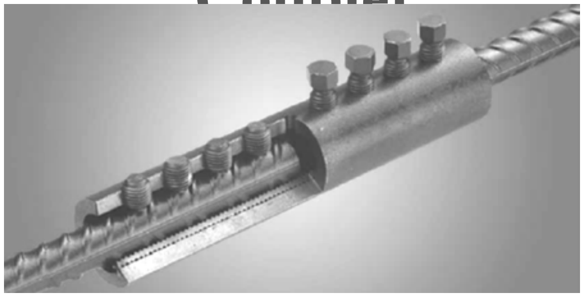


Grouted Sleeve Coupler

[splicesleeve.co

Bar Grip (Swaged) Coupler

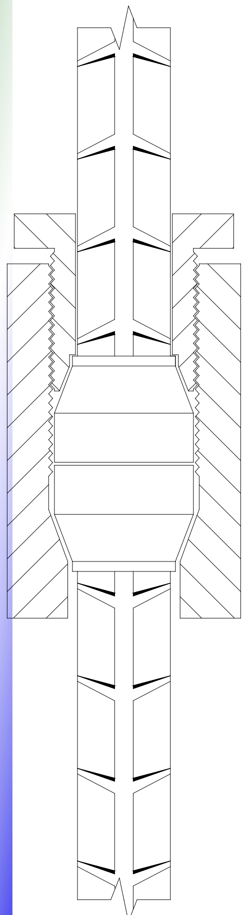
[barsplice.com]



Shear Screw Coupler

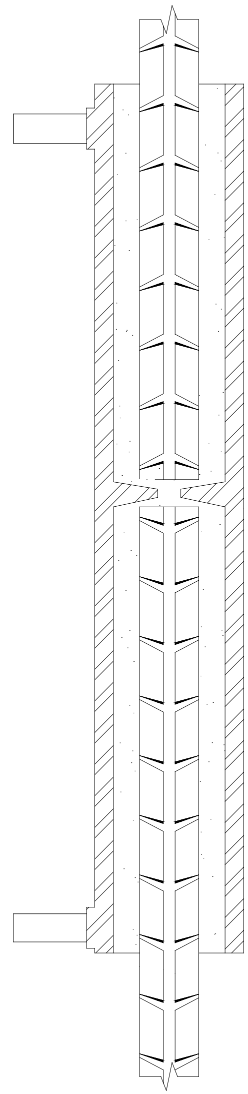
[daytonsuperior.

Mechanical Rebar Couplers – Current Study



Upset Headed (UH)
Ultimate coupler

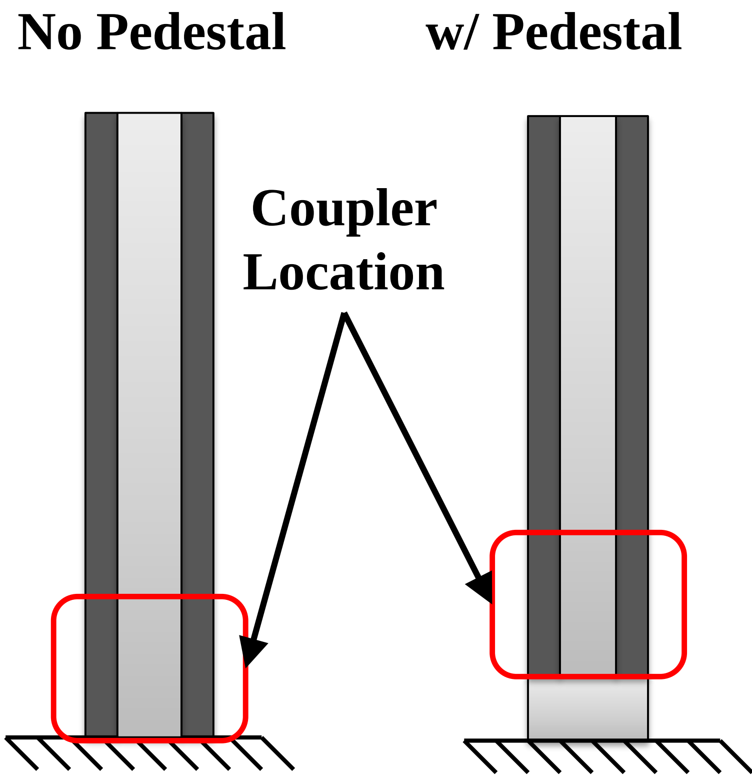
Service Coupler



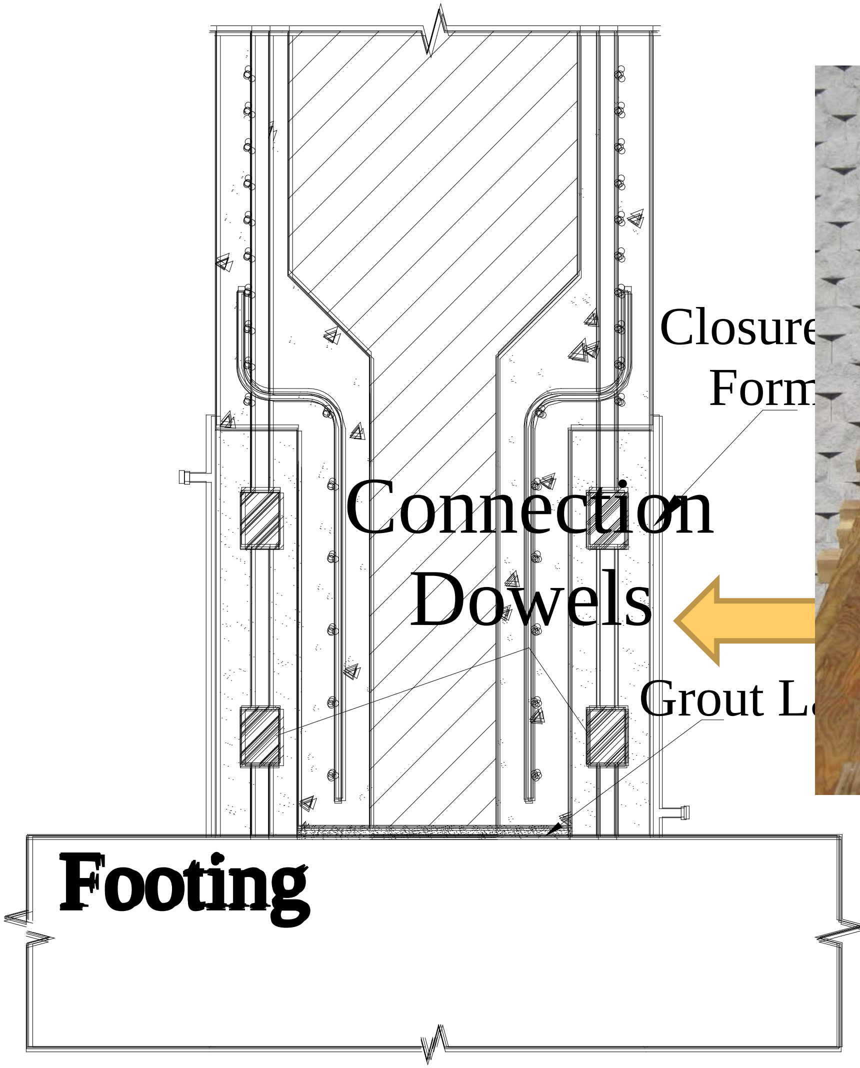
Grouted
Sleeve (GS)

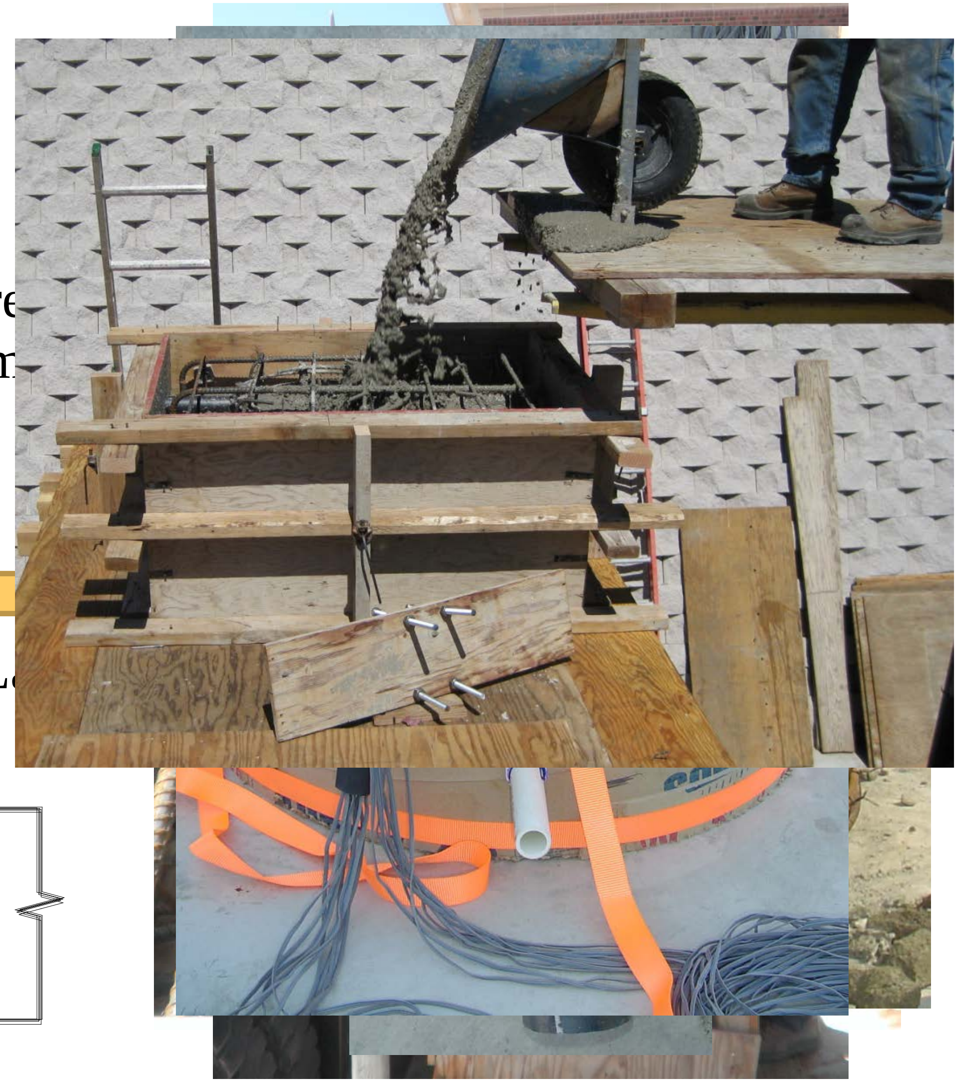
Phase I- 9 Half-Scale Column Models

- Caltrans Seismic Design Criteria (Disp. Ductility ≥ 5)
- Design Details
  - 9ft Tall; 2ft Diameter
  - 11 #8 Longitudinal Steel (1.9%)
  - #3 Spiral @ 2in Pitch (1%)
  - Axial Load = 226kip ($0.1f'_c A_g$)
- Precast Hollow Shell Design
- Filled with SCC
- Use of Precast Pedestal



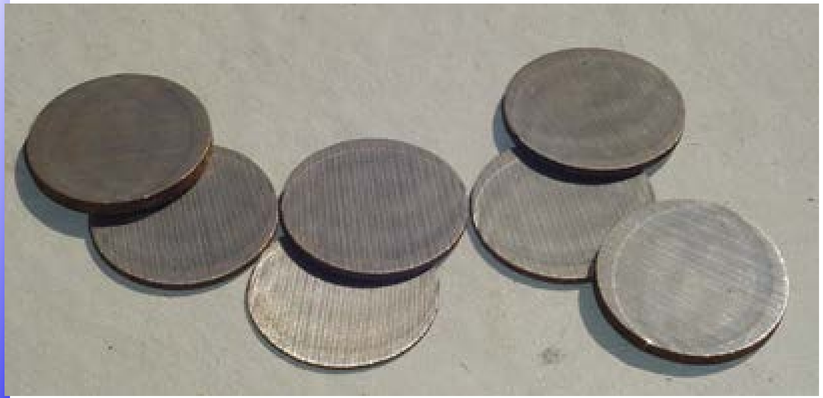
Connection Details – HC Models





HRC Couplers

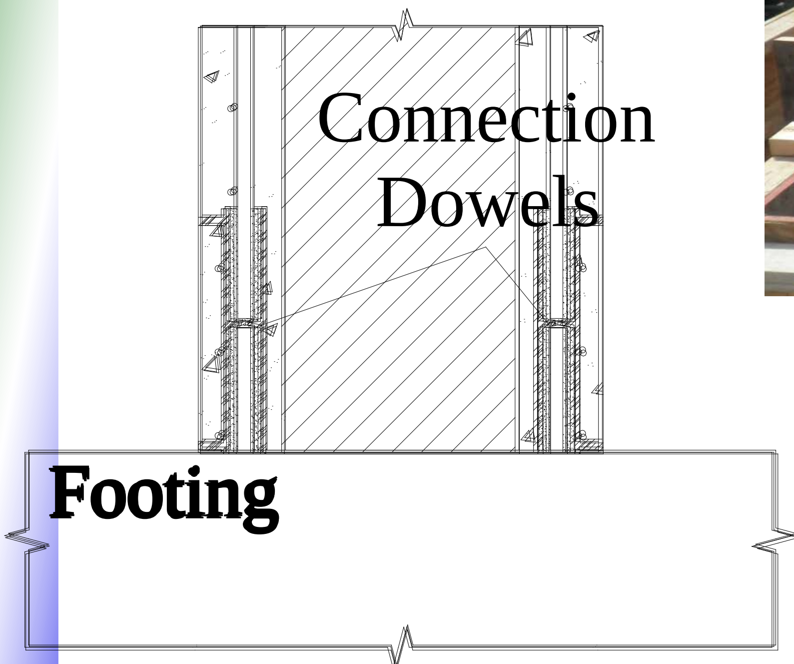
Custom Built Length



Fillers

Close up

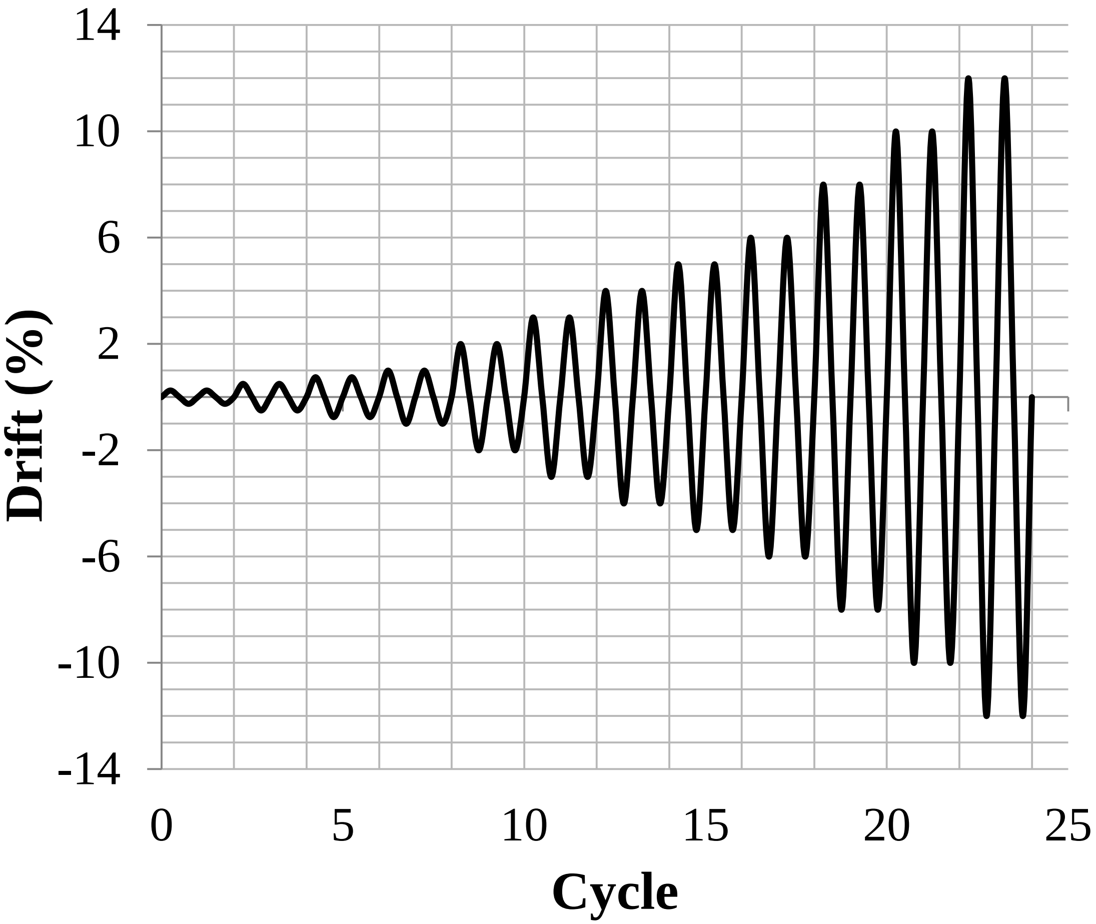
Connection Details – GC Models



Columns with Pedestal

Testing

HC PP
Caltrans
University of Nevada, Reno



14
10
6
2
-2
-6
-10
-14
Drift (%)
0
5
10
15
20
25
Cycle

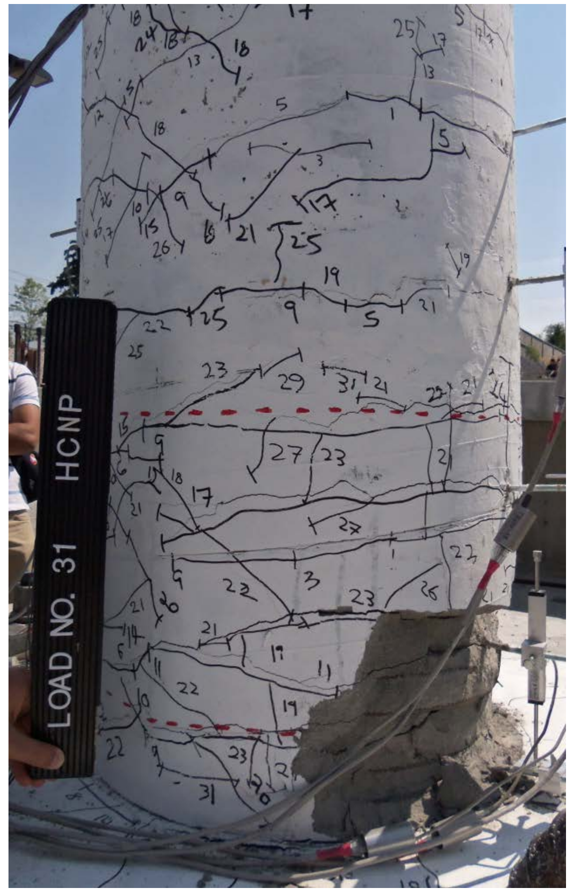
5% Drift – Push Cycle 2

CIP

$\mu_D = 3.6$

F = 65.9 kip

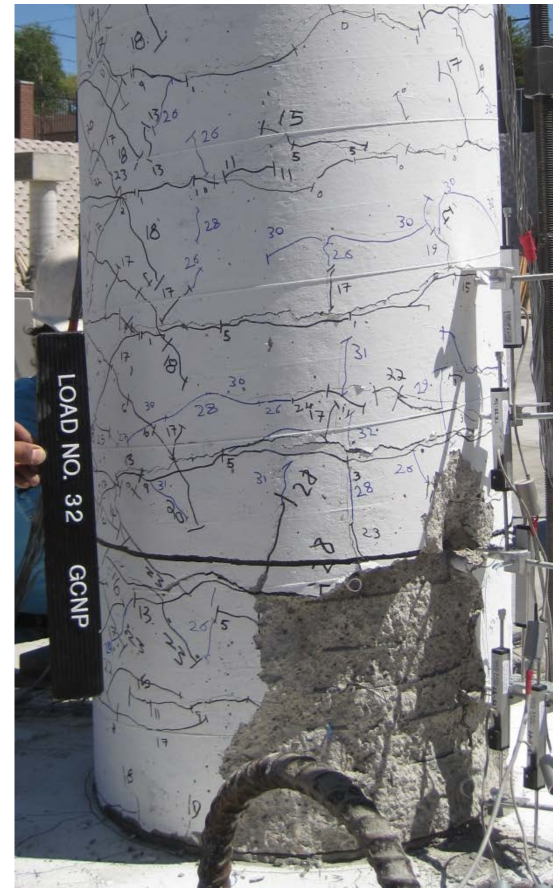
HCNP



$\mu_D = 3.2$

F = 67.8 kip

GCNP



$\mu_D = 3.7$

F = 70.4 kip

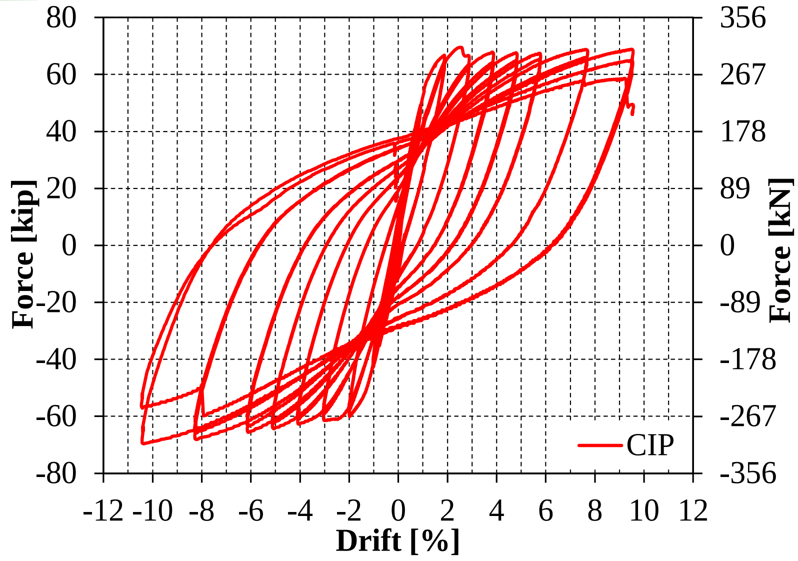
Observations –Damage at Failure

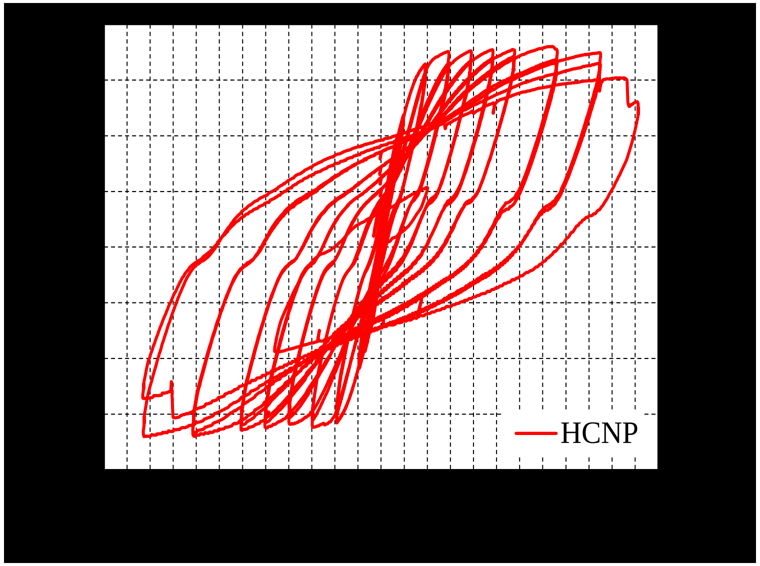
CIP (2nd Cycle 10% Drift)

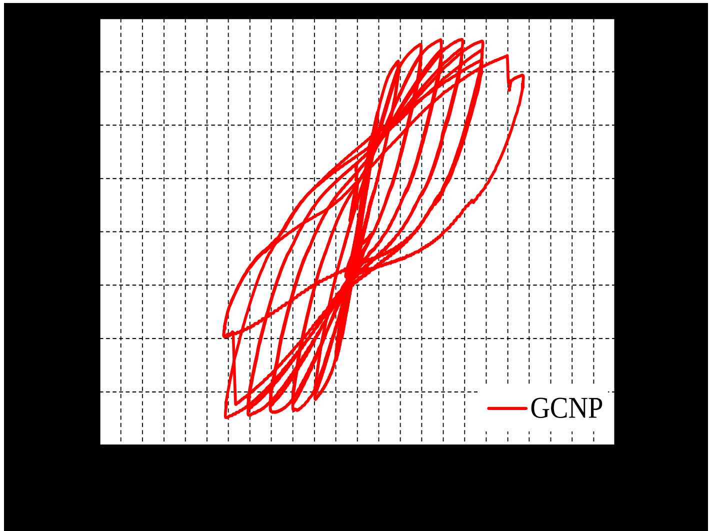
HCNP (2nd Cycle 10% Drift)

GCNP (2nd Cycle 6% Drift)

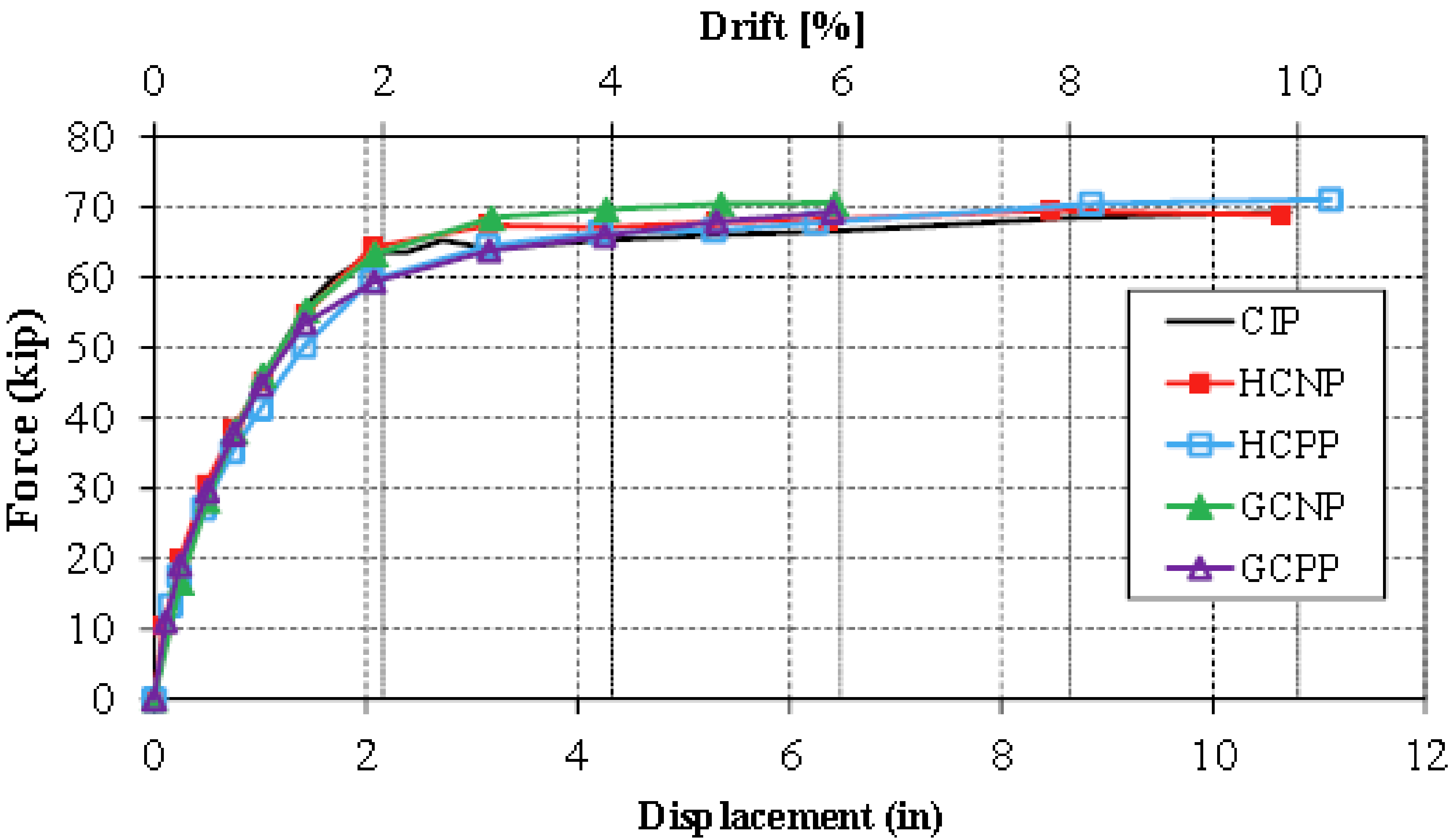
Force-Displacement Responses



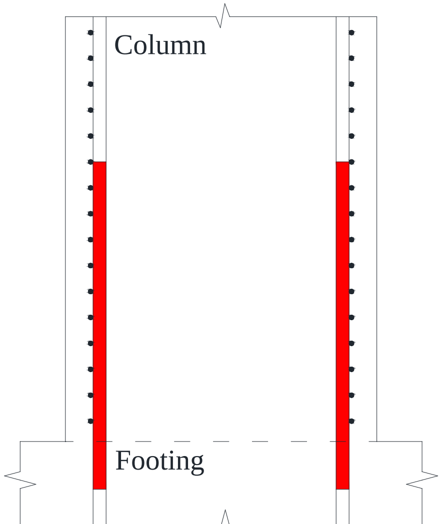




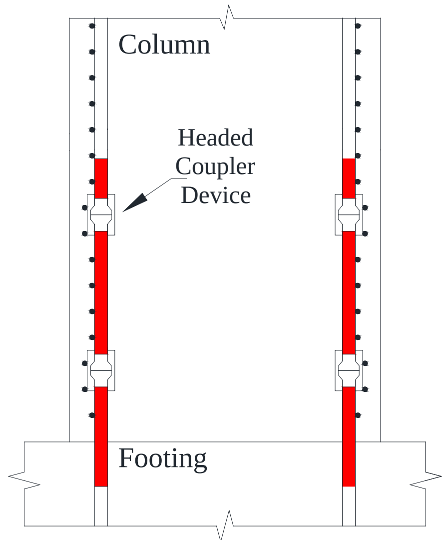
Results - Pushover Curves



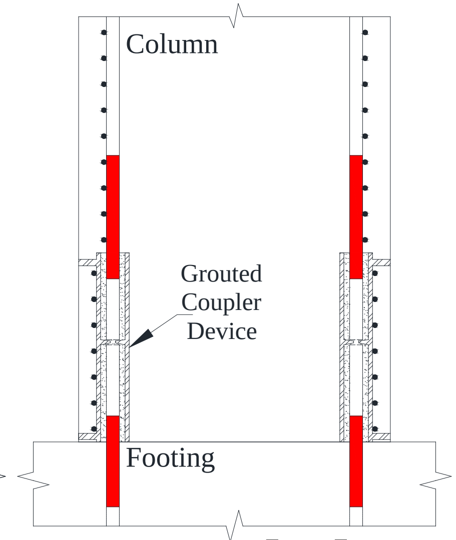
Effect of Couplers on Spread of Yielding



CIP

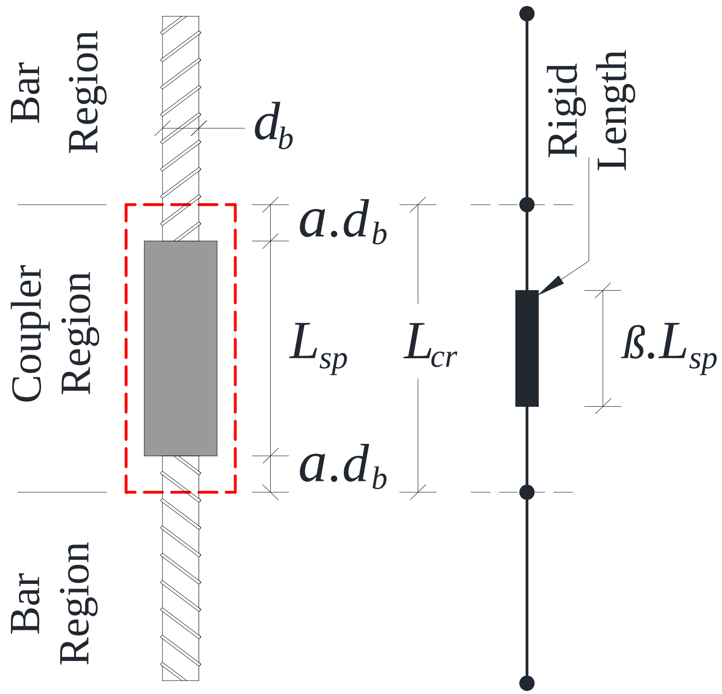


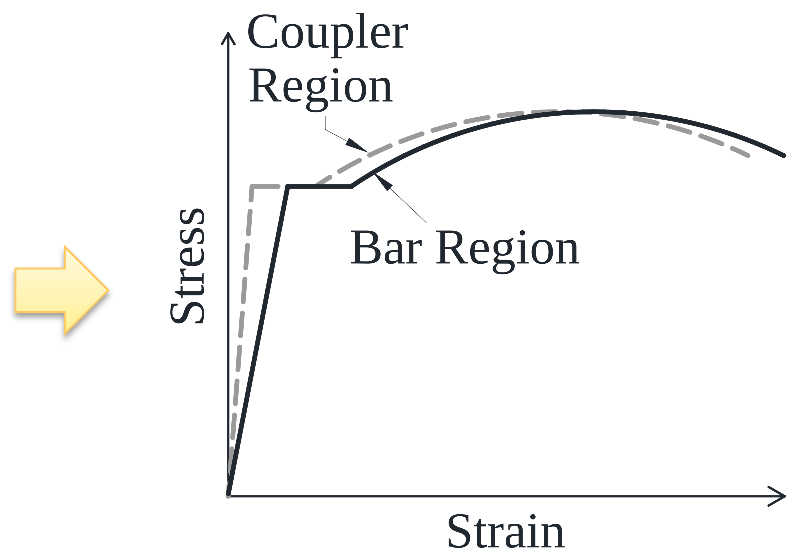
HRC Couplers

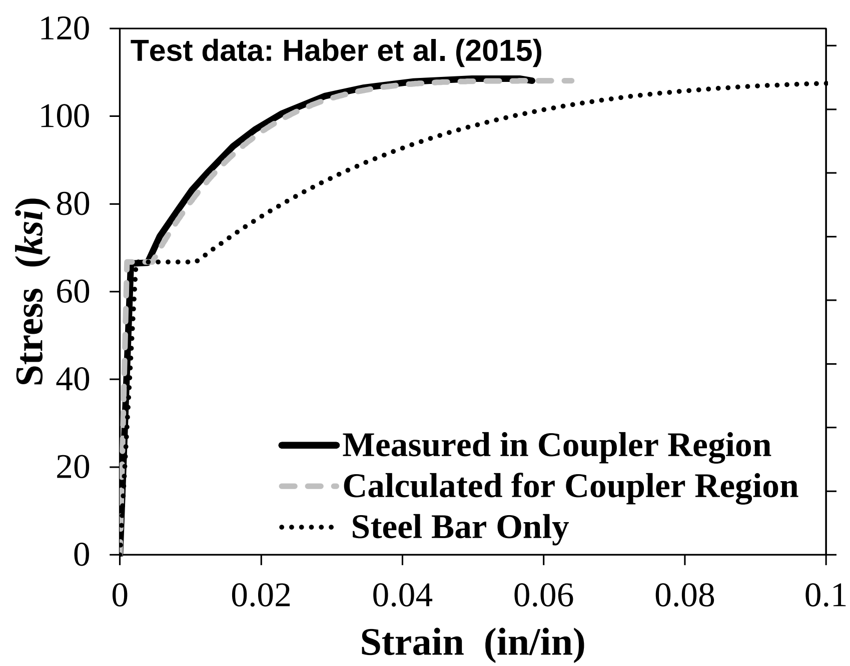


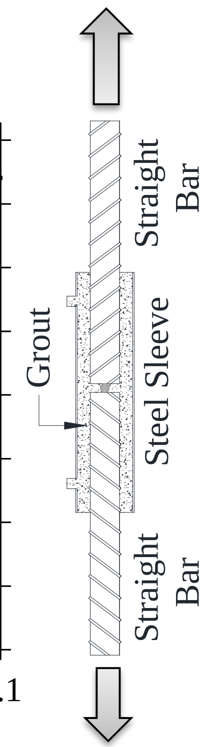
Grouted Sleeve Couplers

Stress-Strain Model for Couplers









$$\frac{\varepsilon_{sp}}{\varepsilon_s} = \frac{L_{cr} - \beta L_{sp}}{L_{cr}}$$

β: Rigid Length Ratio

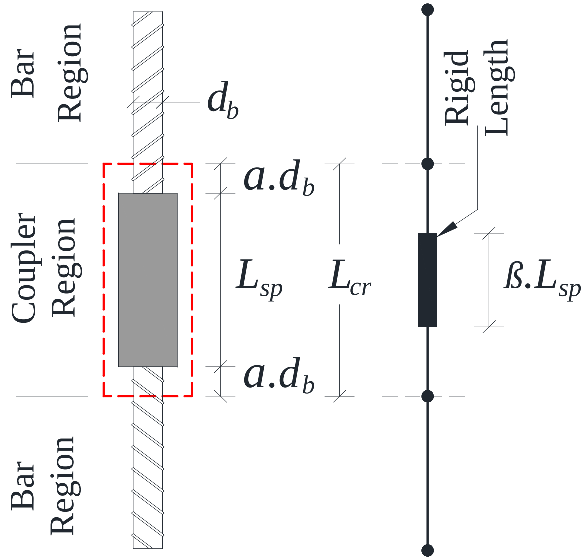
Parametric Study on Columns w/ Couplers

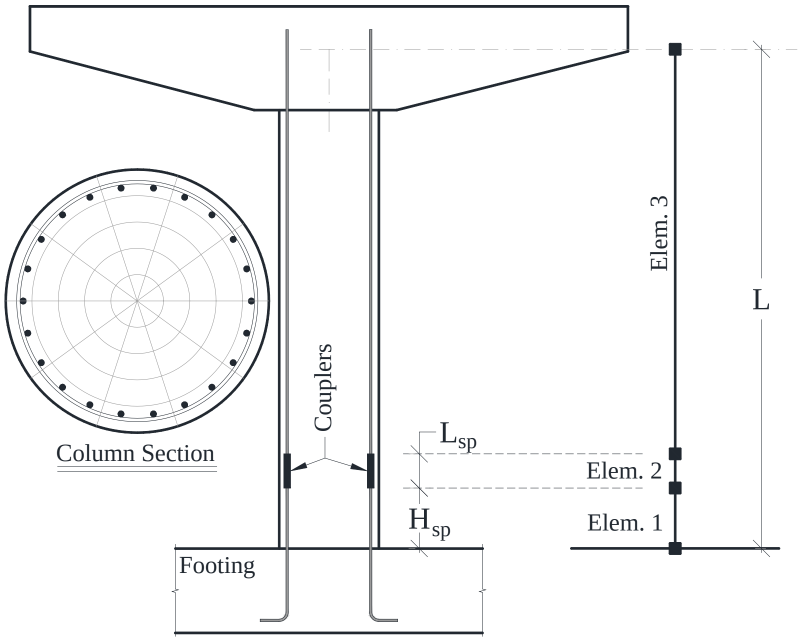
Parameters:

- Coupler Length (L_{sp}= 5d_b, 10d_b, and 15d_b)
- Pedestal Height (H_{sp}=5d_b, 10d_b, 20d_b, and 30d_b)
- Coupler Rigid Length Factors (β = 0.25, 0.50, 0.75)
- Coupler Vertical Spacing (S_{sp} = 2L_{sp} and 4L_{sp})
- Displacement Ductility Capacity (m= 3, 5, and 7)
- Aspect Ratio (4, 6, and 8)
- Axial Load Index (5 and 10%)

More than 660 pushover analyses

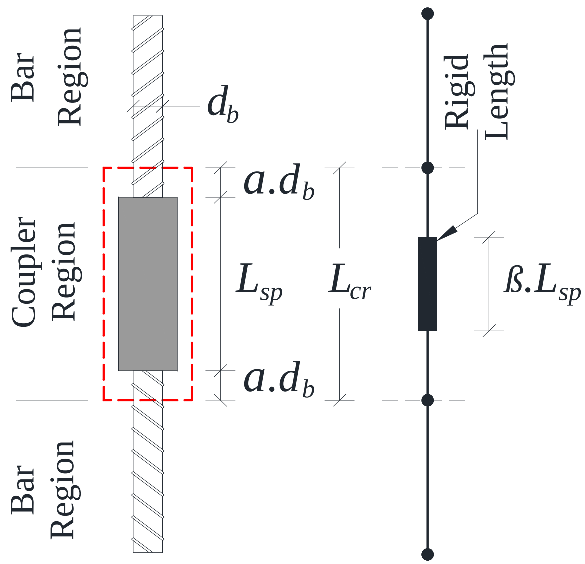
Proposed Ductility Equation

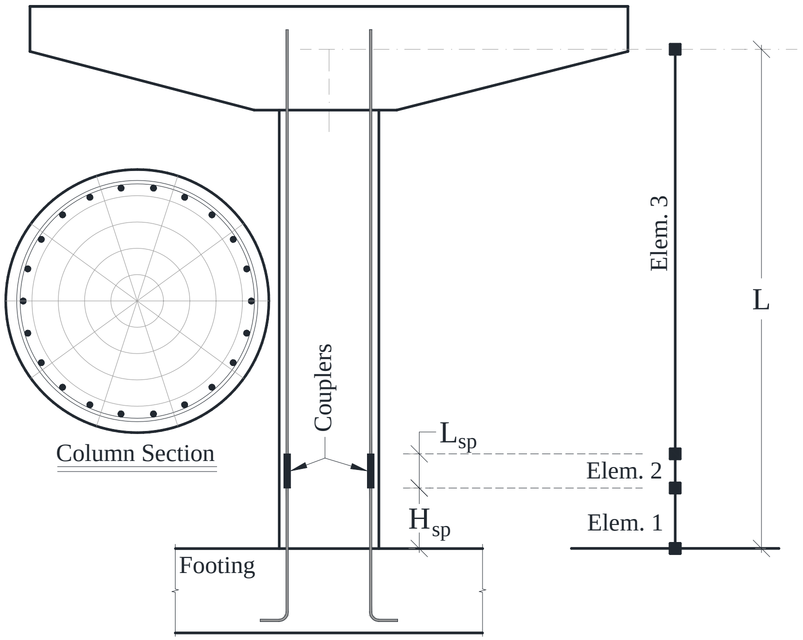




$$\frac{\mu_{sp}}{\mu_{CIP}} = (1 - 0.18\beta)\left(\frac{H_{sp}}{L_{sp}}\right)^{0.1\beta}$$

Proposed Modified Plastic Hinge Length





$$L_p^{sp} = L_p - (1 - \frac{H_{sp}}{L_p})\beta L_{sp} \leq L_p$$

L_p is the AASHTO plastic hinge length:

$$L_p = 0.08L + 0.15 f_{ye} d_b \geq 0.3 f_{ye} d_b$$

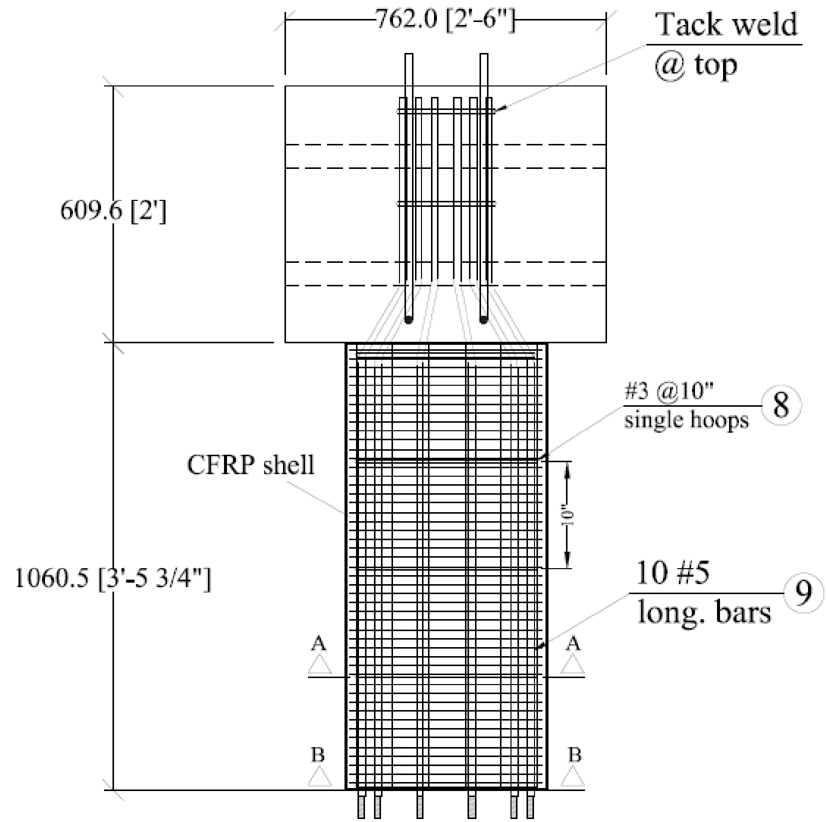
Topic 3 – Couplers in Design for Deconstruction (DfD)

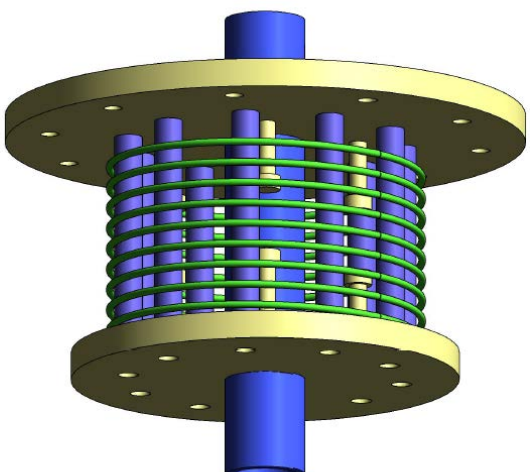
Objectives:

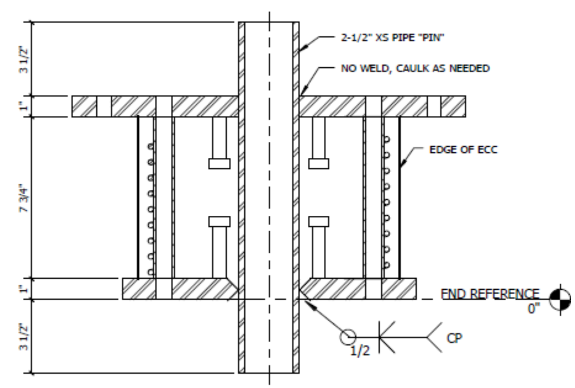
Develop structural member that
1- Withstand strong earthquakes with no or minor Damage so they are useable after earthquakes.
2- Can be disassembled and reused.

Note: 6% of CO_2 emission in the world is from cement factories.

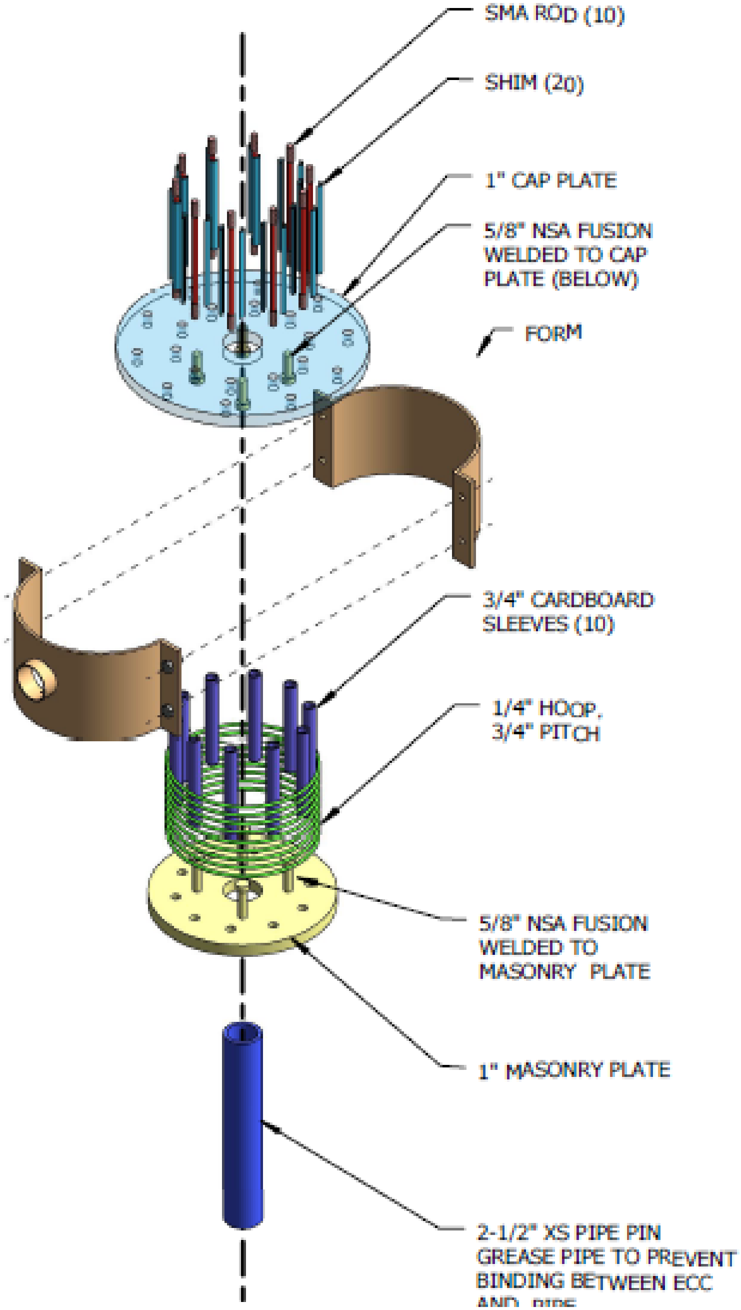
Column Test Models





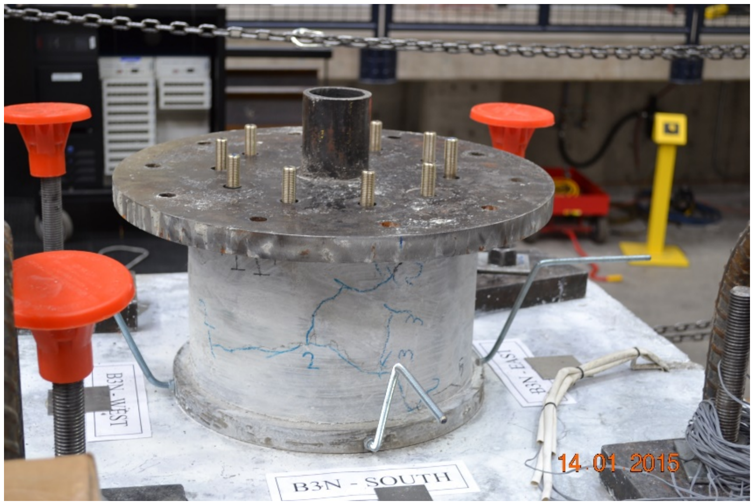


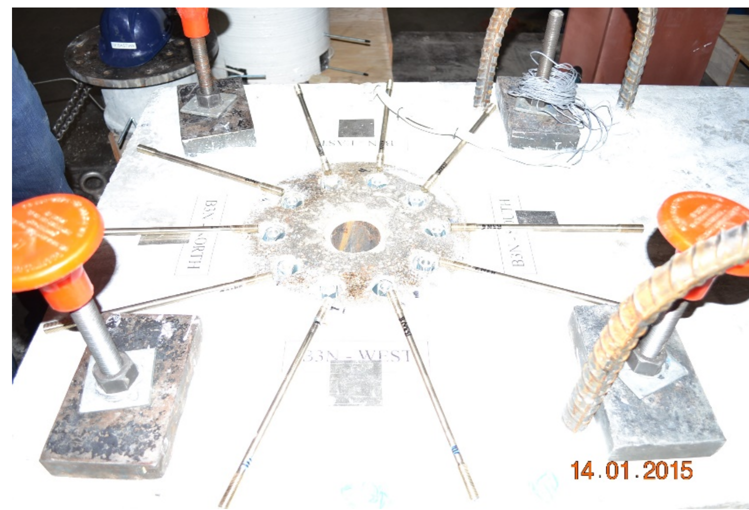
Cu-Al-Mn Bars


SMA ROD (10)
SHIM (20)
1" CAP PLATE
5/8" NSA FUSION WELDED TO CAP PLATE (BELOW)
FORM
3/4" CARDBOARD SLEEVES (10)
1/4" HOOP, 3/4" PITCH
5/8" NSA FUSION WELDED TO MASONRY PLATE
1" MASONRY PLATE
2-1/2" XS PIPE PIN GREASE PIPE TO PREVENT BINDING BETWEEN ECC

Two-Span DfD Bridge Model

After disassembly





Reassembled Bridge Test to Failure (10% drift)

Overview - Shake table test of a reassembled
precast modular 2-span bridge model
with innovative materials (Bridge #2)

2/6/2015
Run 7 - 1.225 x Rinaldi (PGA=1.2 g)

PI: Dr. M. 'Saiid' Saiidi
Graduate Assistant: Sebastian Varela, PhD student
University of Nevada, Reno

Message

- **Bridge earthquake engineering community should be open to possible use of couplers in column plastic hinges.**

- **Columns w/ certain types of couplers perform as well as columns w/ no couplers.**

- **The limited drift capacity of some coupler types would limit their use to low and moderate seismic zones.**

- **Ease of construction varies among different coupler types.**

- **Specific acceptance criteria and design guidelines for “seismic couplers” are needed to provide the coupler option for ABC in moderate and high seismic zones (emerging).**

Today's Speakers

- Elmer Marx, *Alaska Department of Transportation and Public Facilities,* elmer.marx@alaska.gov
- Lee Marsh, *BergerABAM,* lee.marsh@abam.com
- John Stanton, *University of Washington,* stanton@u.washington.edu
- M. Saiid Saiidi, *University of Nevada, Reno,* saiidi@unr.edu

Get Involved with TRB

- Getting involved is free!
- Join a Standing Committee (http://bit.ly/2jYRrF6)
- Become a Friend of a Committee (http://bit.ly/TRBcommittees)
  - Networking opportunities
  - May provide a path to become a Standing Committee member
- ***Sponsoring Committee: AFF50***
- For more information: www.mytrb.org
  - Create your account
  - Update your profile

Receiving PDH credits

- Must register as an individual to receive credits (no group credits)
- Credits will be reported two to three business days after the webinar
- You will be able to retrieve your certificate from RCEP within one week of the webinar

TRB turns 100 on November 11, 2020

100 YEARS
2020
TRB

Help TRB:

- Promote the value of transportation research;
- Recognize, honor, and celebrate the TRB community; and
- Highlight 100 years of accomplishments.

Learn more at

www.TRB.org/Centennial

MOVING IDEAS: ADVANCING SOCIETY—100 YEARS OF TRANSPORTATION RESEARCH