Photo courtesy of TriMet

Western Bridge Engineers' Seminar

September 6-8, 2017
Portland Marriott Downtown Waterfront | Portland, Oregon

Innovations in Bridge Design and Construction - WSDOT

Bijan Khaleghi,
State Bridge Design Engineer

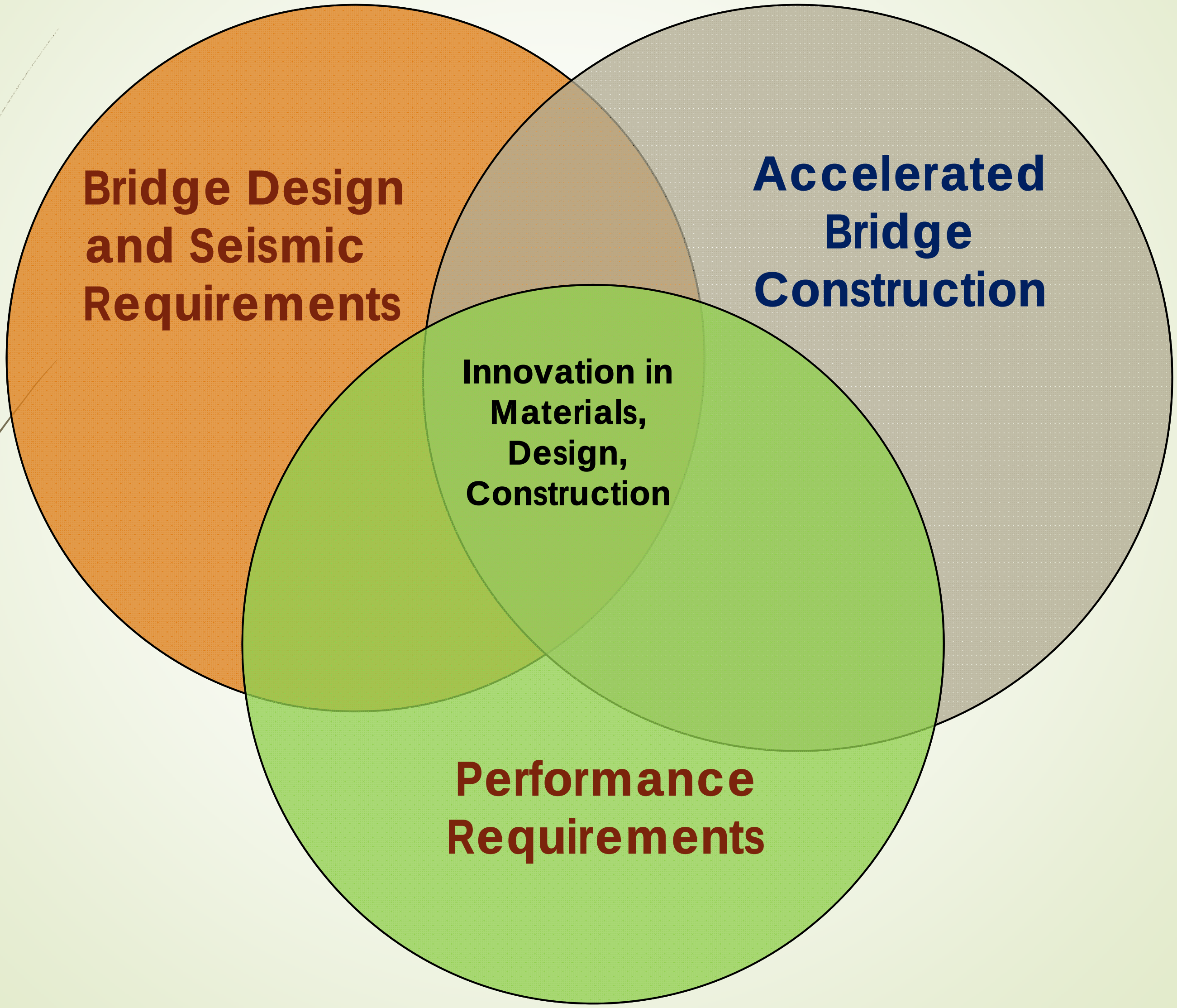
Washington State Department of Transportation
Bridge and Structures Office

Presentation Outline

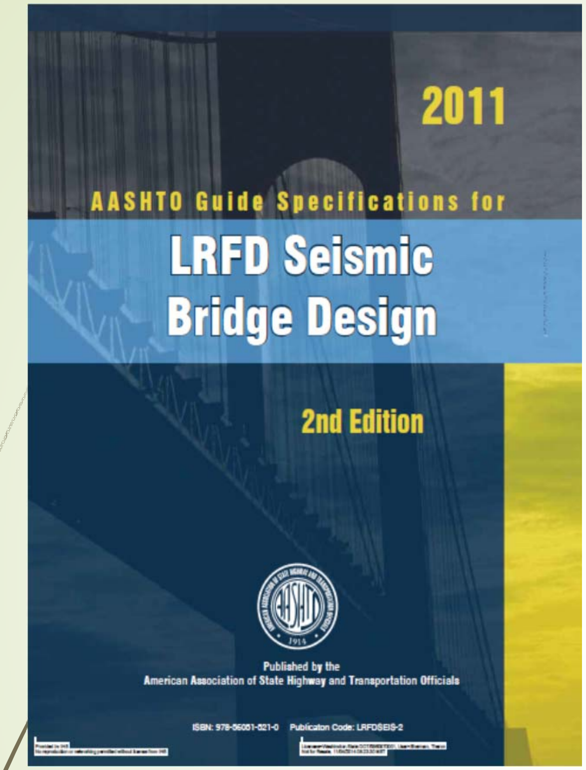
Innovations in Bridge Design: Seismic - ABC

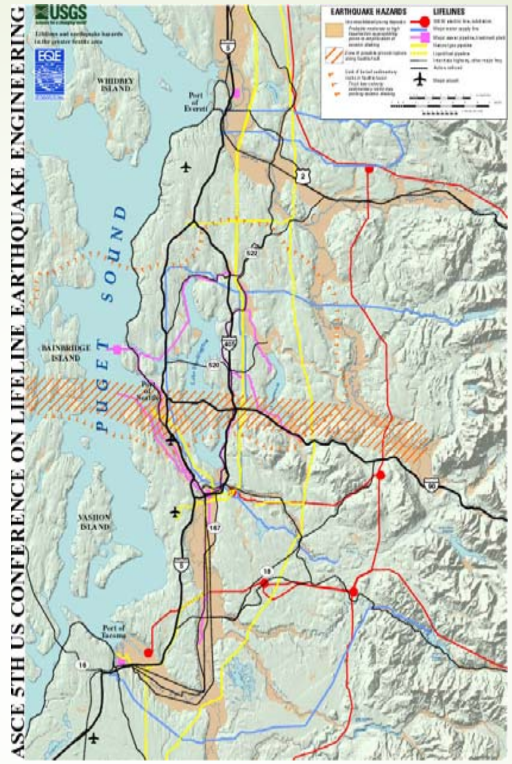
- Focus: Connections - emulative and other systems
- Seismic design requirements and PBSD
- ***Recent WSDOT Research Projects:***
  - ABC – HFL
  - Super-Elastic Smart materials - IBRD
  - CFST and Connections
  - WFDG-UHPC Connections
- ***Alternative ABC Connections Utilizing UHPC***

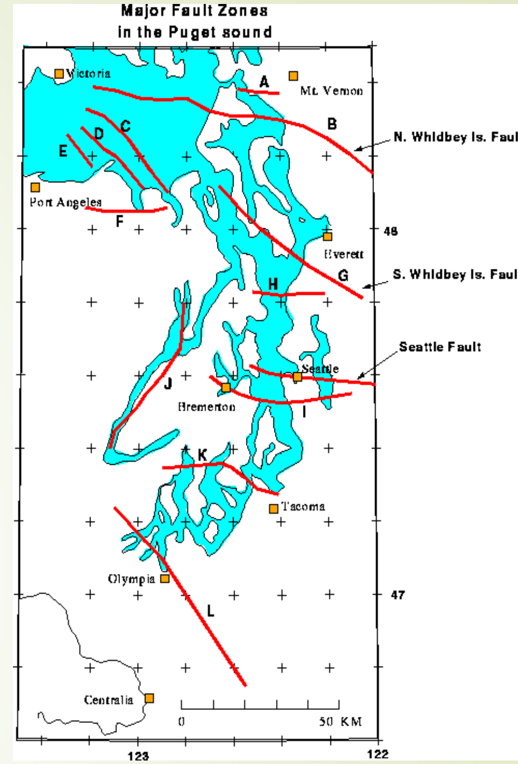
Bridge Design – ABC & Seismic Challenges



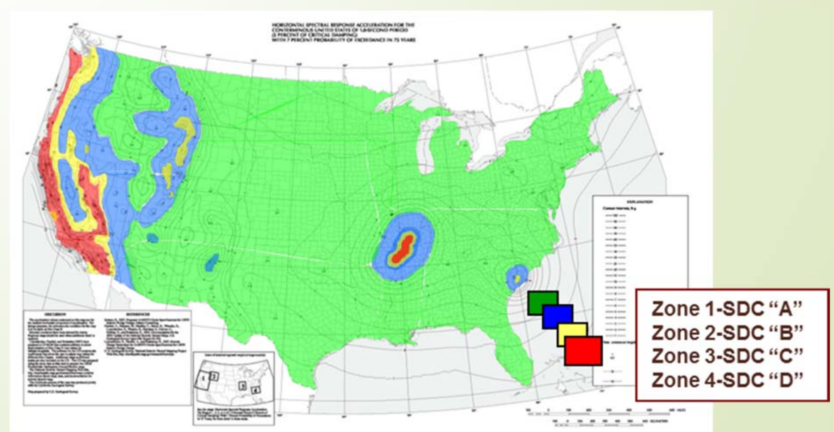
Seismic Design Requirements



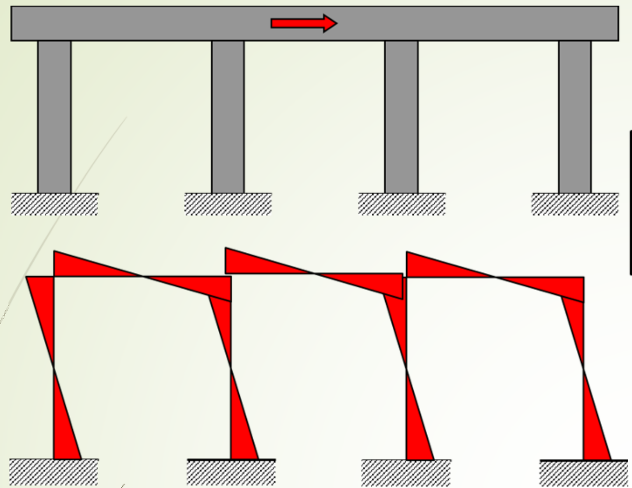




- AASHTO Guide Specifications for LRFD Seismic – **DBD**
- 2014 Seismic Hazard Maps, and Site Coefficients
- Cascadia, Basin Effect, Mega EQ, Tsunami, etc.



Seismic Design Requirements - Connections



PBES bent connections

ABC

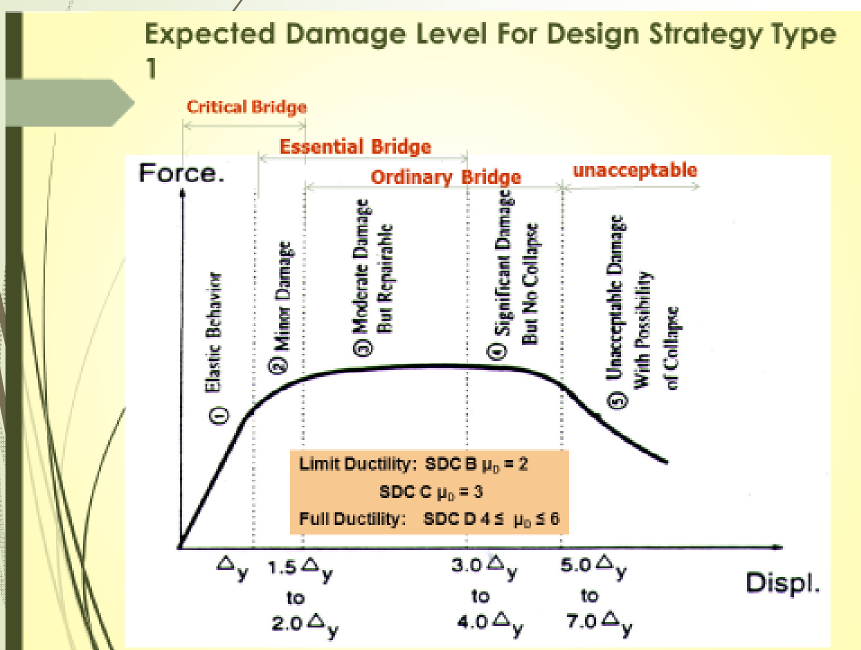
- Easy to assemble.
- Generous tolerances.
- Fast in the field.
- Common materials.

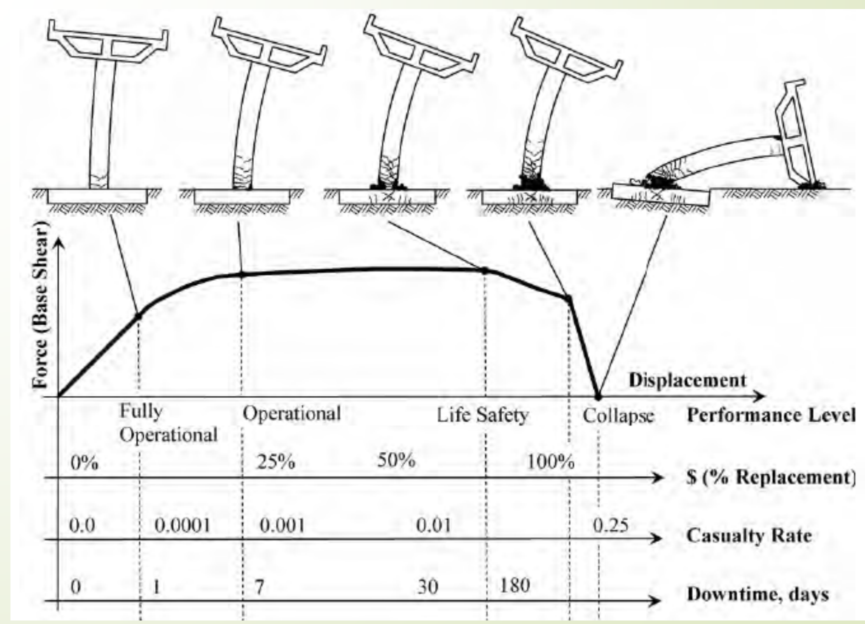
Seismic

- Continuous load path.
- Robust.
- Avoid eccentricities.
- Energy Dissipation.
- Protect brittle elements.
- No stress concentrations.

So what is the problem?

Requirements for ABC and seismic often conflicting.
Need approaches that solve both problems together.





Seismic Resiliency – goals for recovery times for transportation systems in terms of hours, days, weeks, months, and years

TARGET STATES OF RECOVERY: WASHINGTON'S TRANSPORTATION SECTOR

	Event occurs	0–24 hours	1–3 days	3–7 days	1 week–1 month	1 month–3 months	3 months–1 year	1 year–3 years	3 + years
Interstate 5									
Puget Sound (center & north end)				Red	Yellow	Green		×	
South end (Chehalis south)			Red	Yellow	Green		×		
Interstate 90									
Puget Sound (Snoqualmie Pass west)				Red	Yellow	Green		×	
Cascades to eastern WA (Snoqualmie to Idaho)			Red	Yellow	Green		×		
Interstate 405									
South end (Tukwila to I-90)			Red	Yellow		Green		×	
North end (I-90 to Lynnwood)				Red	Yellow	Green		×	
Ferry operations		Red		Yellow	Green		×		
Floating Bridges									
SR 520				Red	Yellow	Green		×	
I-90			Red	Yellow	Green		×		
Hood Canal		Red	Yellow	Green	×				
25% of major & minor arterials		Red	Yellow	Green	×				
50% of major & minor arterials		Red		Yellow	Green	×			
75% of major & minor arterials			Red	Yellow		Green	×		
90% of major & minor arterials			Red		Yellow		Green	×	
Airports		Red		Yellow	Green			×	
Airport for emergency traffic		Yellow			×				
Ports and navigable waterways				Red	Yellow	Green		×	
Rail (freight & passenger)				Red	Yellow	Green		×	
Mass transit[3]									

Red: **Minimal** (A minimu
emergency respond
critical supplies.)

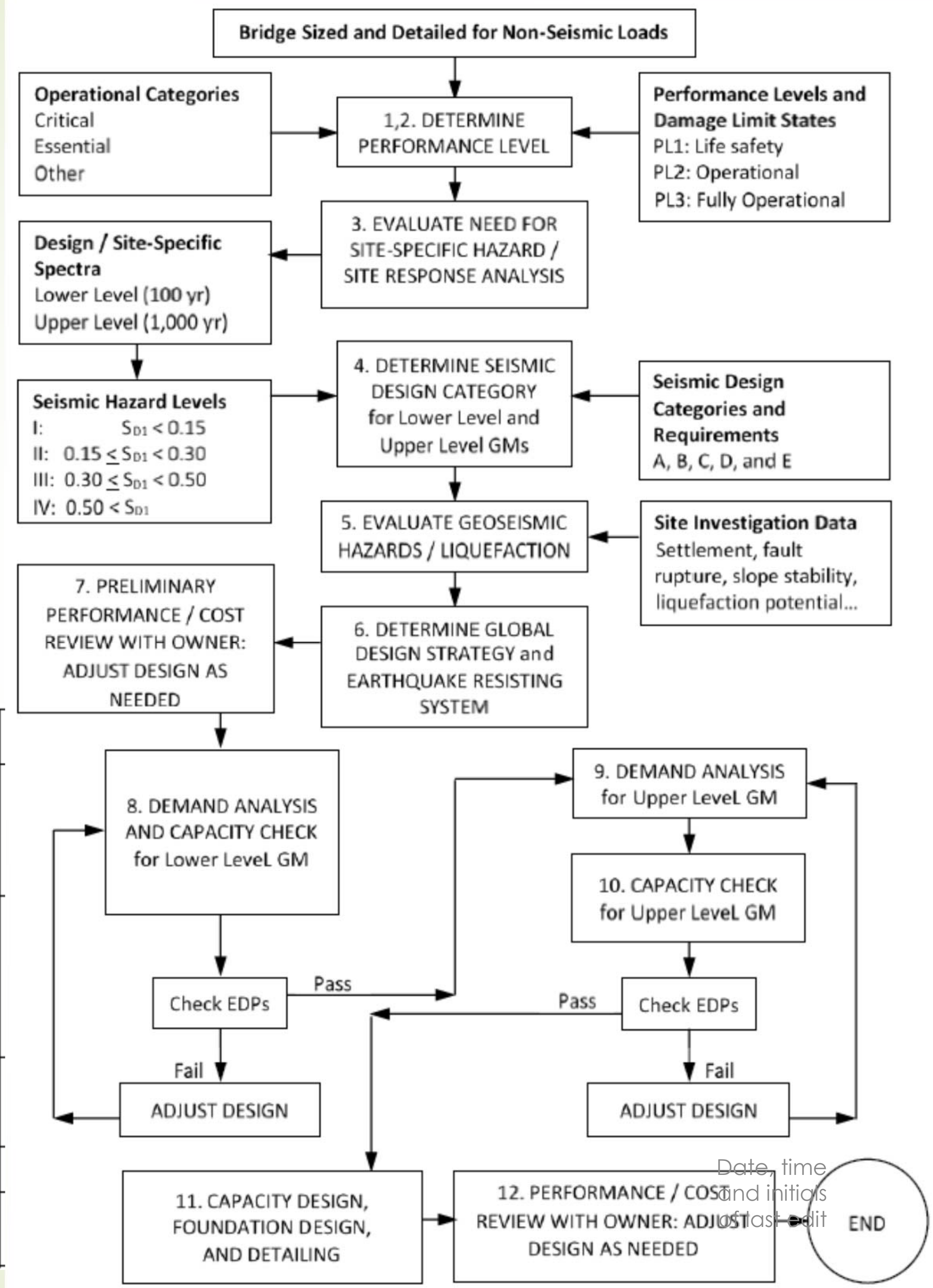
Yellow: **Functional** (Althoug
get the economy m
accommodated. Th
lower speed limits.)

Green: **Operational** (Resto
service has been re
and to work.)

PBSD Flowchart

Basic Elements in Performance-Based Design of Bridges

Element	No.	Description
Bridge Operational Categories	3	Critical Essential Other
Performance Levels and Associated Damage Descriptors and Engineering Design Parameters	3	PL1: Life safety PL2: Operational PL3: Fully Operational
Earthquake Ground Motion Levels	2	Lower Level (100 yr) Upper Level (1,000 yr)
Seismic Hazard Levels	4	I, II, III, IV
Seismic Design Categories	5	A, B, C, D, and E



Unacceptable Performance

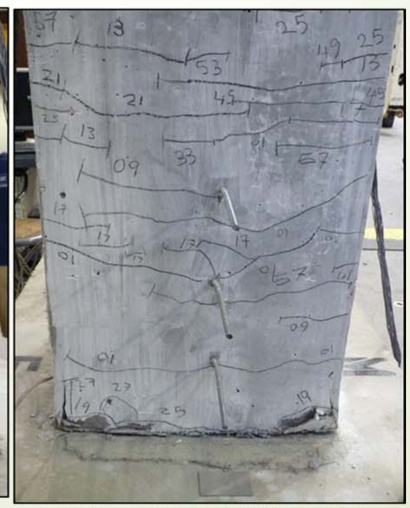
Lack of Seismic Design, Ductility & Confinement

Desirable Performance –Adequate Seismic Design, Ductility & Confinement

Damage at End of Testing

SR99-RC (8% Drift)

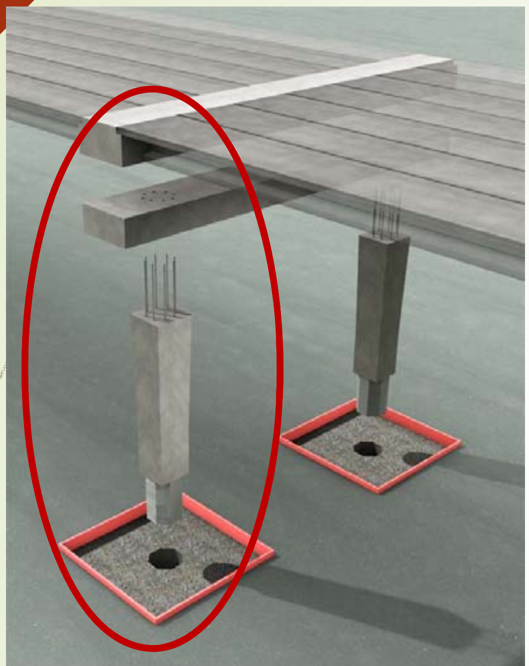
SR99-LSE (12% Drift)



SR99-SSE (10% Drift)

Damage after undergoing 10% drift

Seismic Performance of Precast Bents Used for ABC

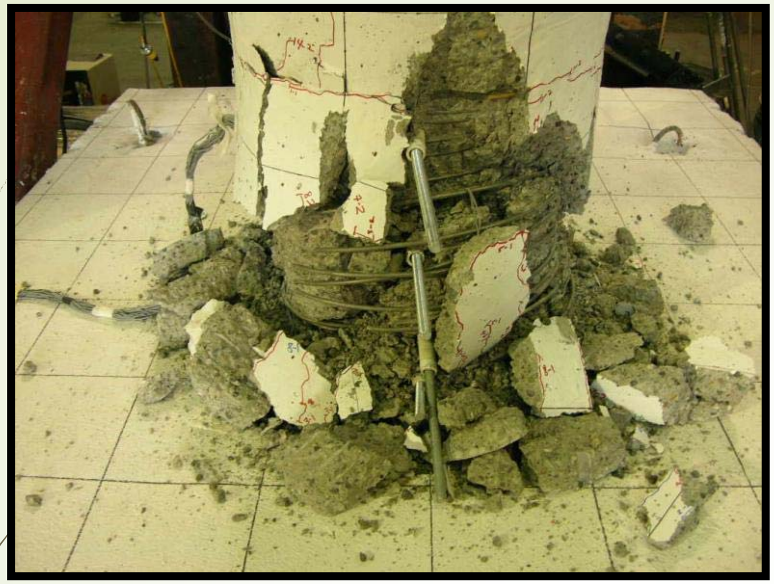


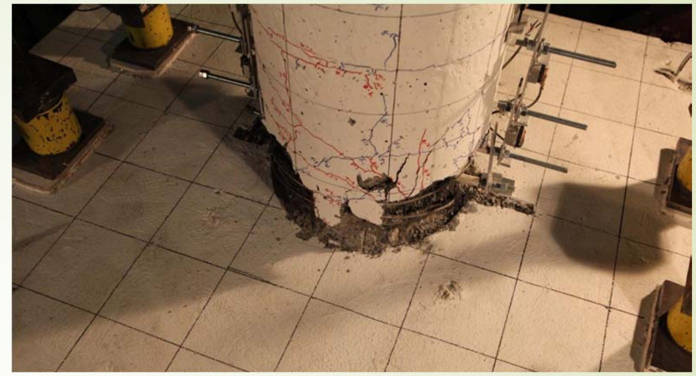
- Integral Moment Resisting Connection
- Member socket connection at base
- Grouted ducts at precast cap connection
- Two-stage cap: Lower Precast, Upper CIP

Highways for LIFE Project

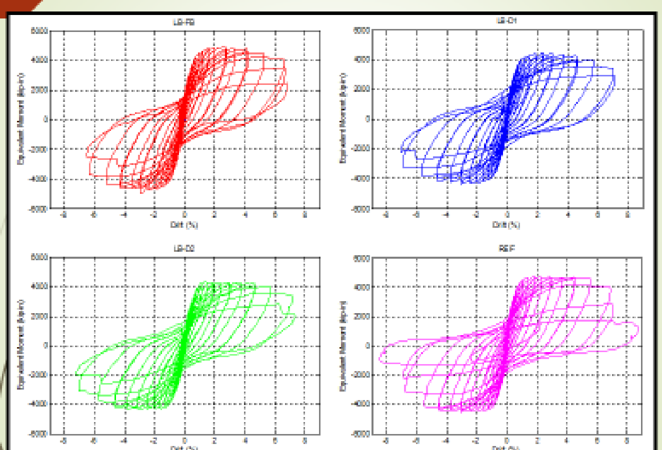
- Funded by FHWA's Highways for LIFE Technology Partnerships Program
- Project Team:
  - BergerABAM – Grant Awardee
  - University of Washington
  - Washington State DOT
  - Concrete Technology Corporation
  - TriState Construction
- More Information @ www.fhwa.dot.gov/hfl

Column-to-Spread Footing and Shaft Connection Tests





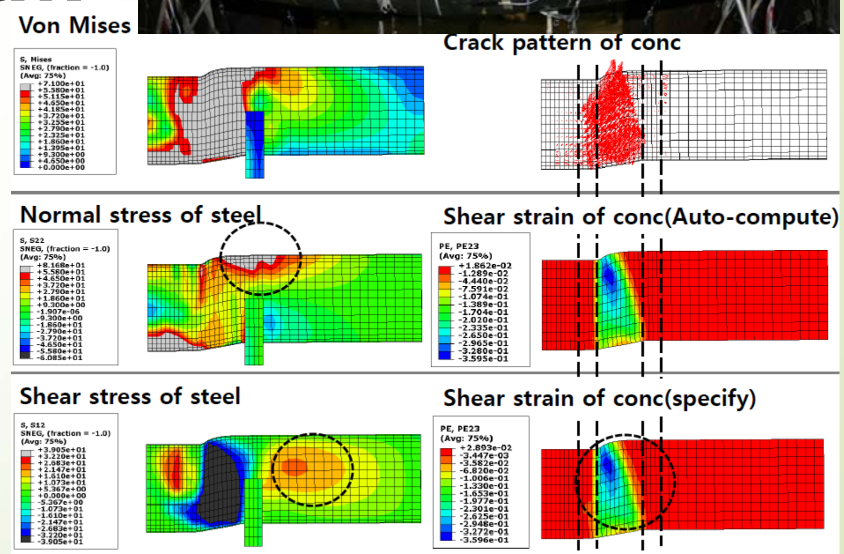
Moment vs. Drift



Same response for precast and CIP

Concrete Filled Steel Tubes - CFST

- ✓ Steel casing is used for Structural Capacity
- ✓ Structural welds at every splice and spirals
- ✓ Bond between Concrete and Steel Casing
- ✓ Design Guidance for Axial, Flexural & Shear
- ✓ Connections to Cap and Foundation for Seismic
- ✓ CFST & RCFST Embedment into Cap/Foundatio
- ✓ Long term performance and longevity of CFST



✓ University of Washington Professors Roeder and Lehman

CFT-to-Cap Connections

Connection design recommendations:

a. Design of the annular ring

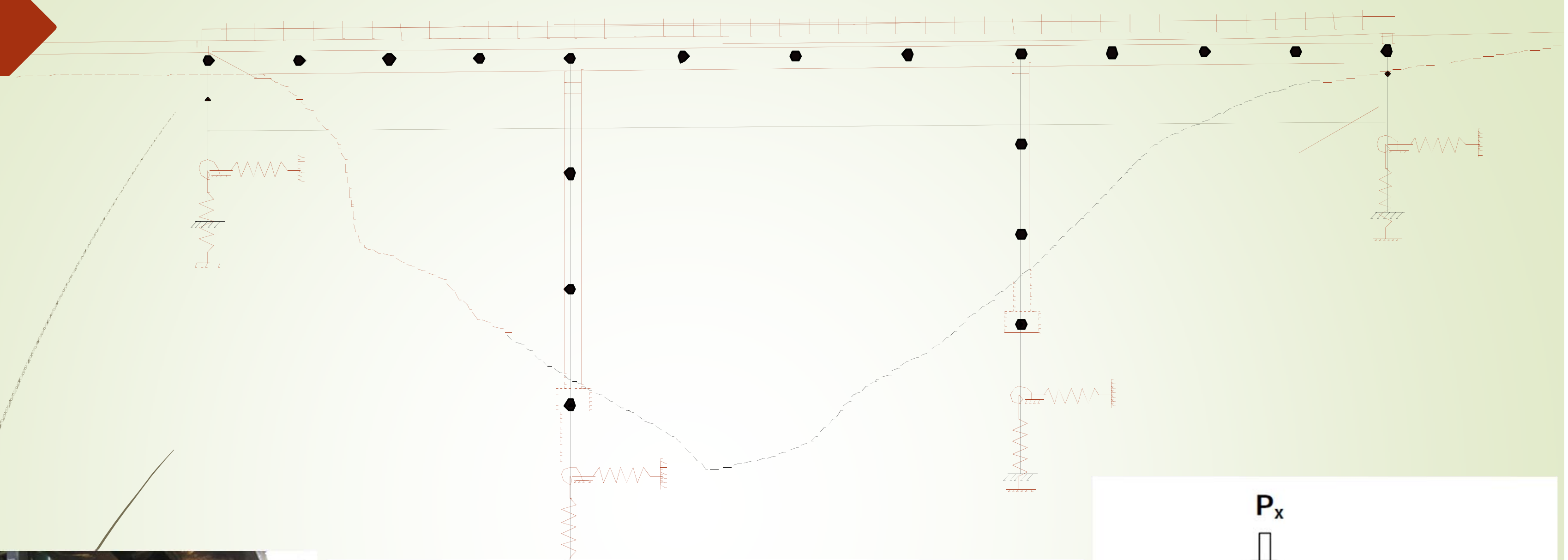
b. Determination of the embedment depth

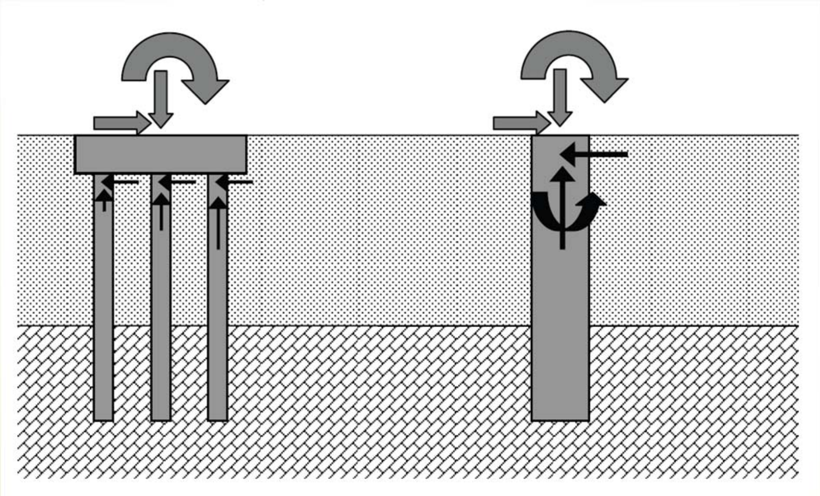
c. Punching shear evaluation in the cap

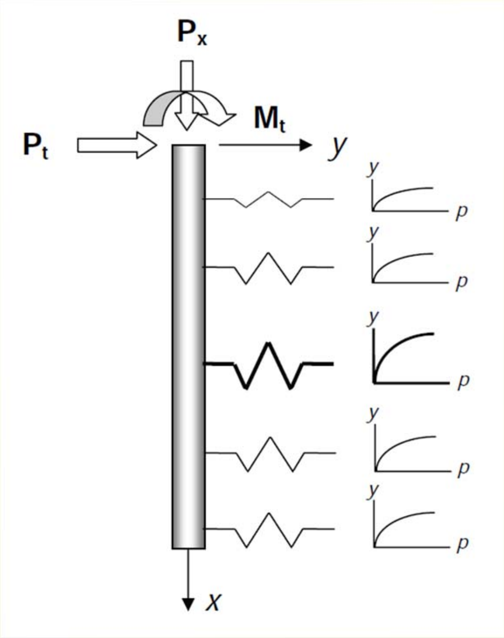
d. General design of the cap for flexure and shear

An alternative to the annular ring - reinforcing cage to splice the CFT to the cap.

CFST Design Consideration: Lateral Loads







Ductility

Deep Foundation

Lateral EQ Load

Eastbound Nalley Valley Project

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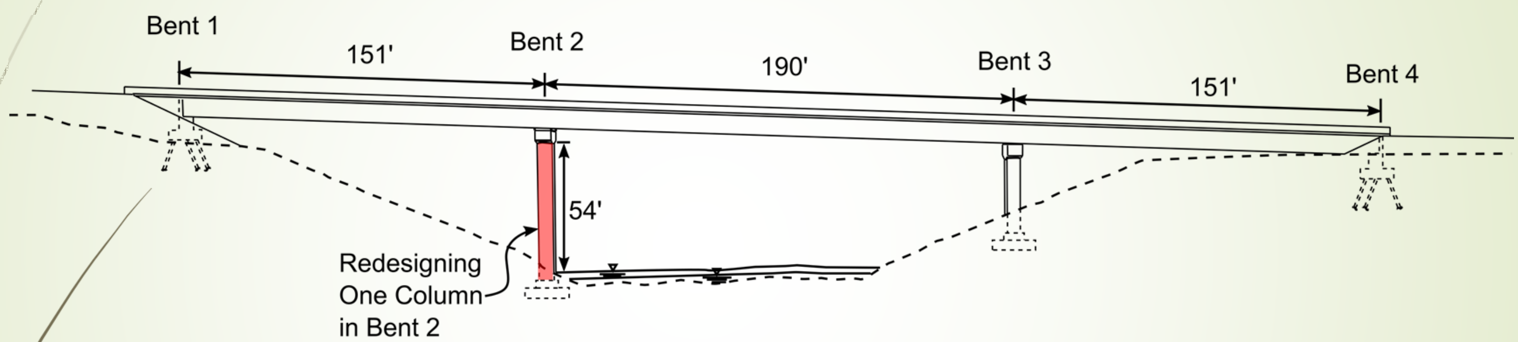
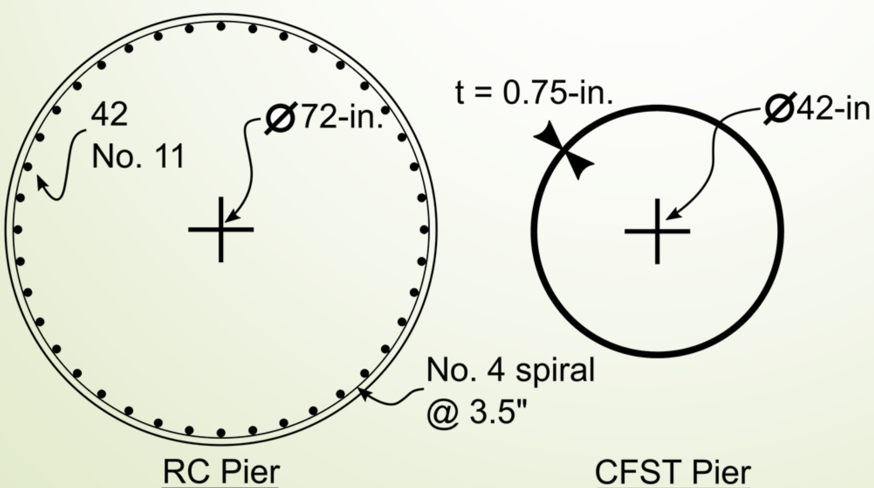
ABC and Practical Design Solution

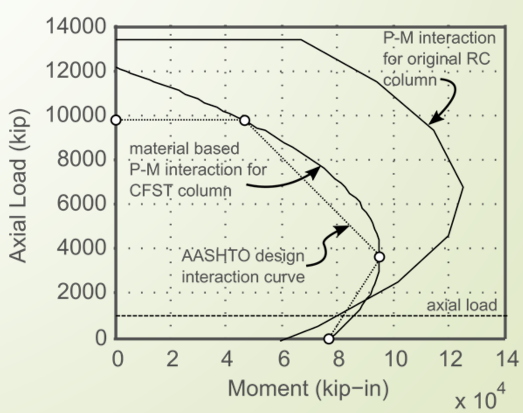
- CFST Pile-Column 3 ft dia.
- CFST Ring Connection to Cap
- Driven Pile-Column (no Reinf)
- Smaller column and Cap

CFST- ABC & Practical Design Solution

- CFT eliminate the need for reinforcing steel and forming
- Reduce construction time and cost
- CFT Offers Smaller columns and crossbeams resulting in less mass for seismic design







Self Centering Bridge System suited for Seismic Resiliency

Superelastic Materials:

Shape Memory Alloy (SMA) and

Engineered Cementitious Composite (ECC)

for Bridge Columns

Challenges:

- Superelastic Materials are not addressed by either of the AASHTO LRFD Bridge Design Specifications or AASHTO Seismic Guide Specifications

NCHRP Project – LRFD Guide Specs for non-emulative systems

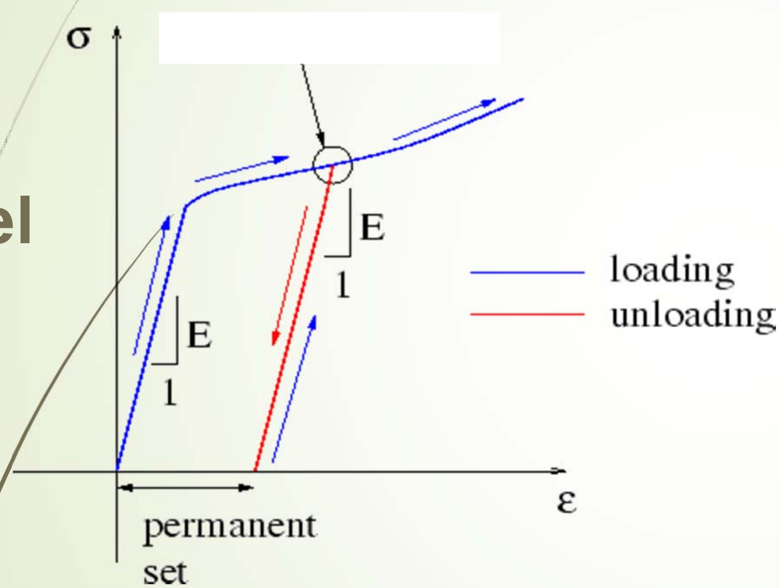
SR 99 South Access to Tunnel

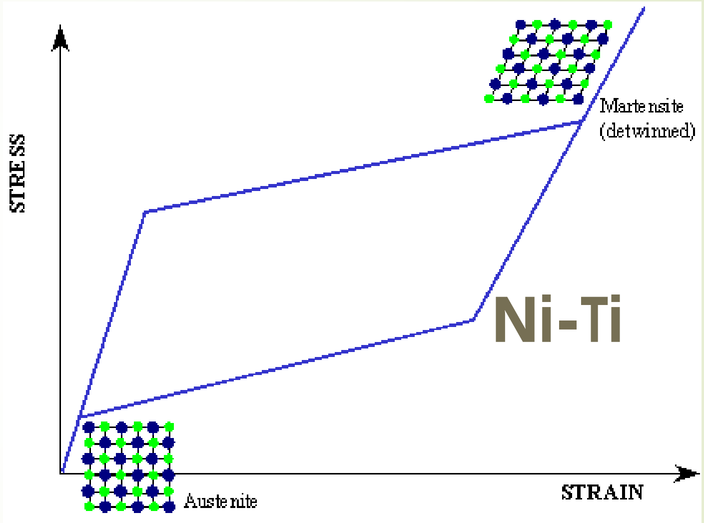
Innovative Materials: SMA for Bridge Columns

Superelastic Nickel-Titanium Shape Memory Alloy (SMA) Bars

- Reduce residual displacements

Steel





- Challenges with SMA:
  - SMA Availability
  - Head bar for mechanical splice
  - Mechanical splice required in hinge region

Typical test setup at UNR

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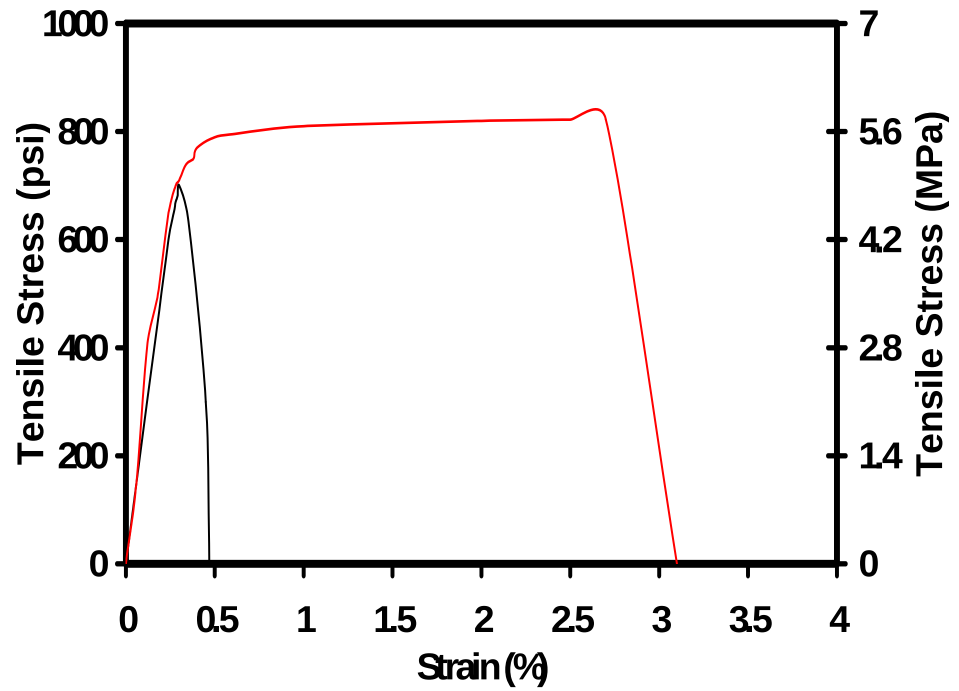
FHWA Innovative Bridge Research and Deployment (IBRD)

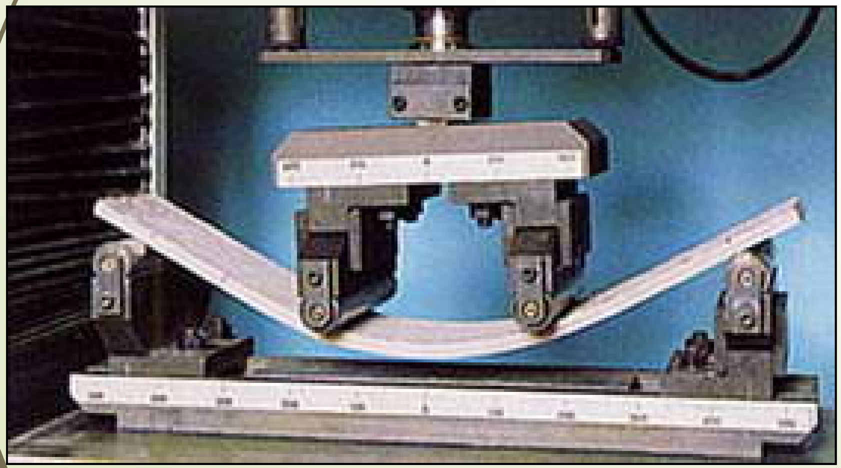
- Three - 0.3 Scale Columns
  - 2 Incorporating SMA and ECC
  - 1 Conventional RC
- 62 in clear height
- 18 in x 18 in cross-section

Professor Saiidi University of Nevada-Reno

Innovative Materials ECC

- Engineered Cementitious Composites (ECC)
- Reduce damage to hinge zone

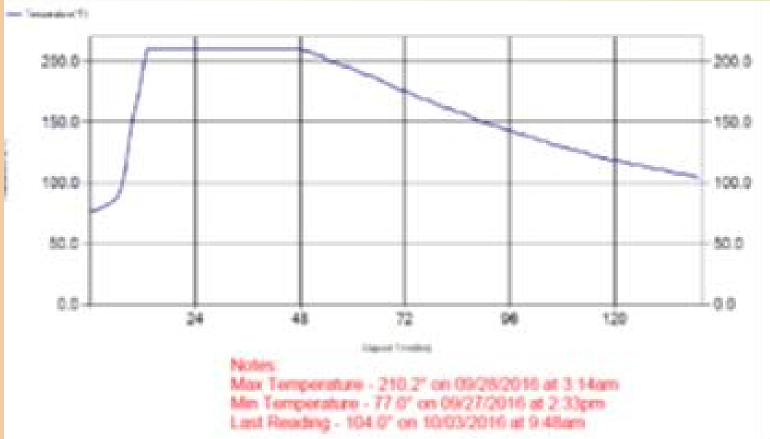




Mobile mixing of ECC for placement

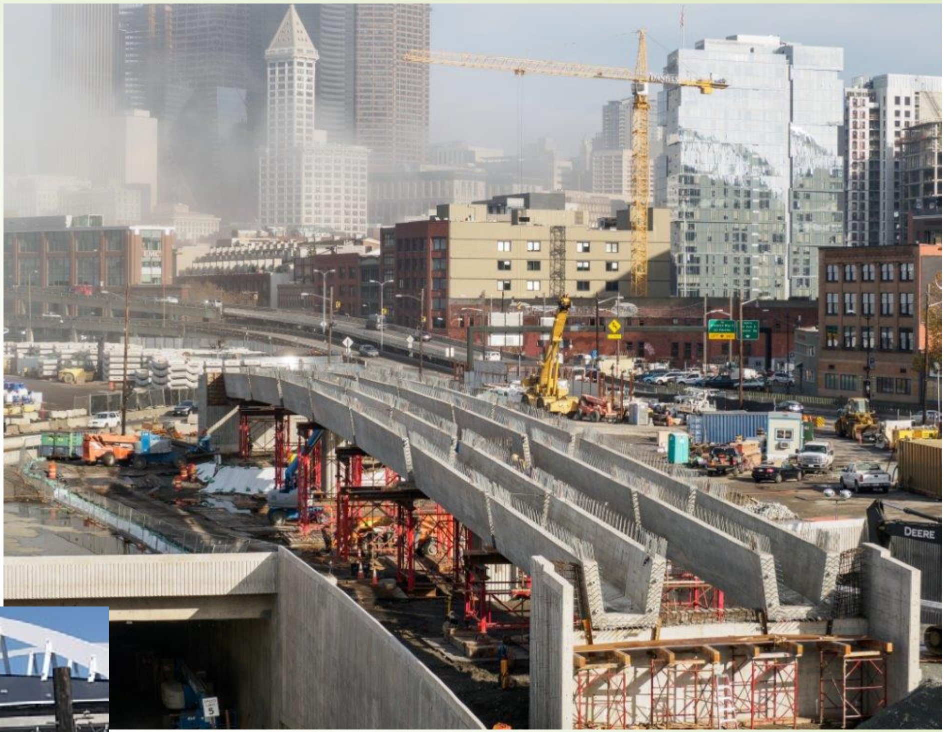
Challenges with ECC:

- ECC, 10 times of conventional concrete
- Batch and sack dry ingredients
- Mix on site with mobile high shear mixer
- Place by bucket at top of column
- Use cooling pipes similar to mass concrete



Bridge Construction

SMA/ECC used for AWV Precast PT Spliced-Girder Bridge

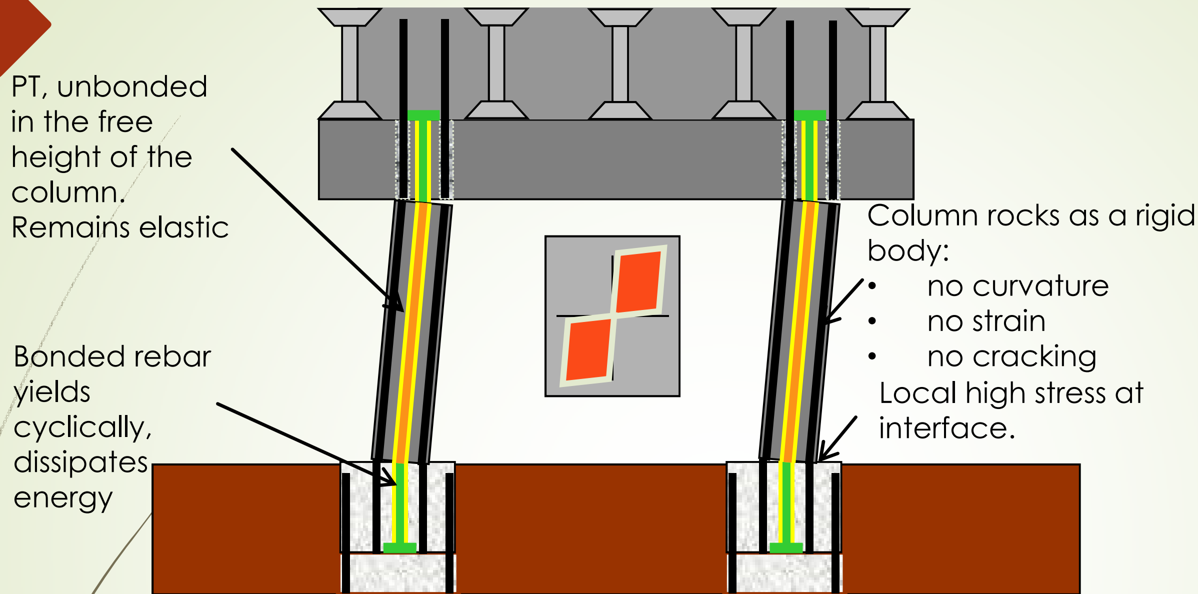


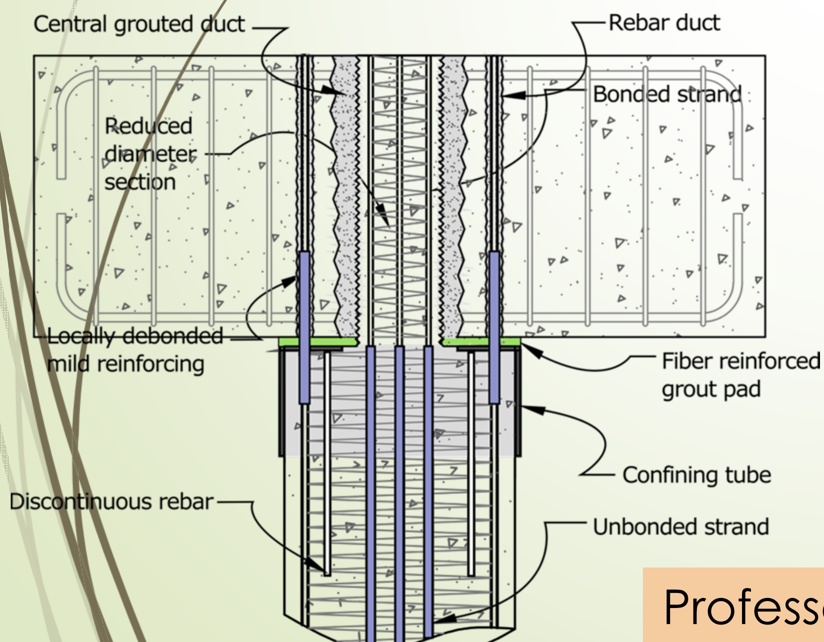
SMA

- ASTM A706 = $1 / lb. , SMA = $92 / lb.
- Mechanical splice required in hinge region

Date, time and initials of last edit

Seismic Resiliency – Self Centering Prestressed Columns for Bridge Bent



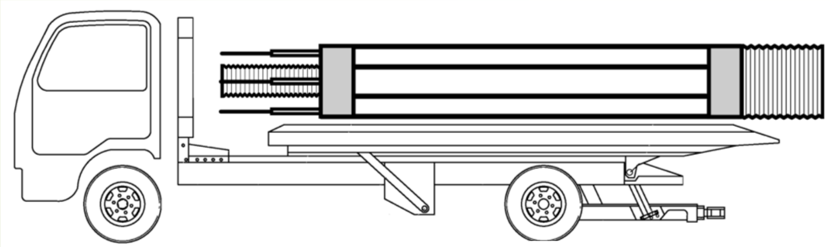


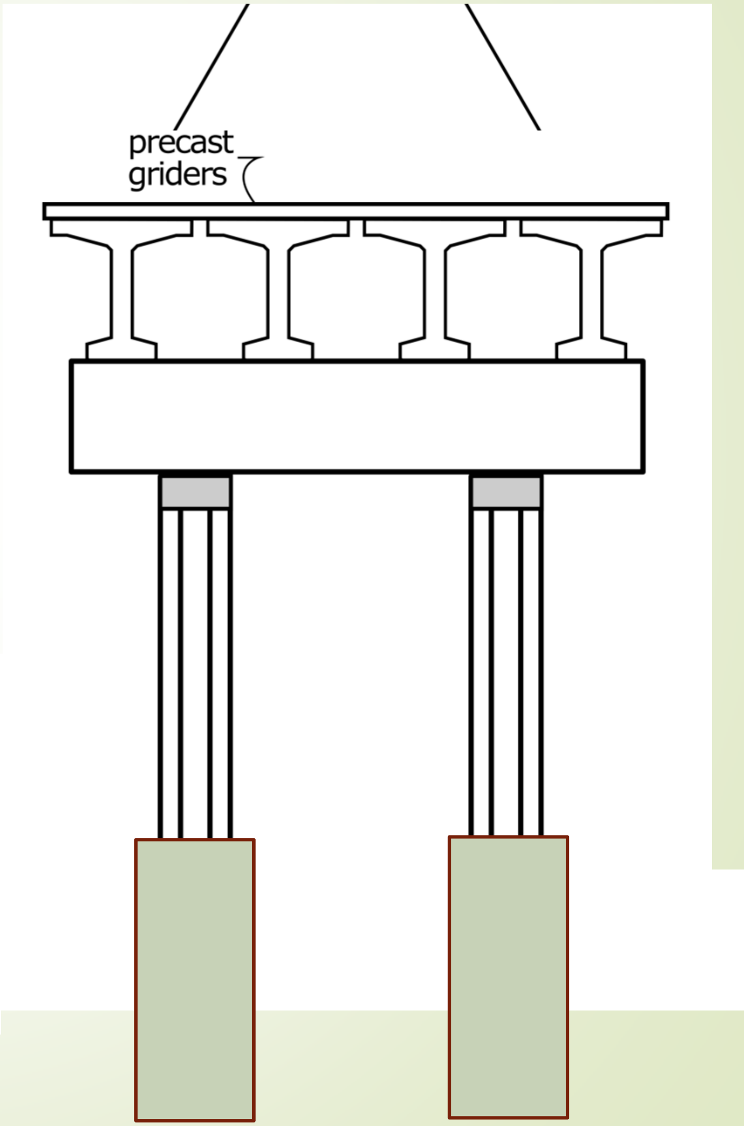
Professors Stanton/Eberhard – UW, Test at UNR

Pre-T Precast system

Construction sequence

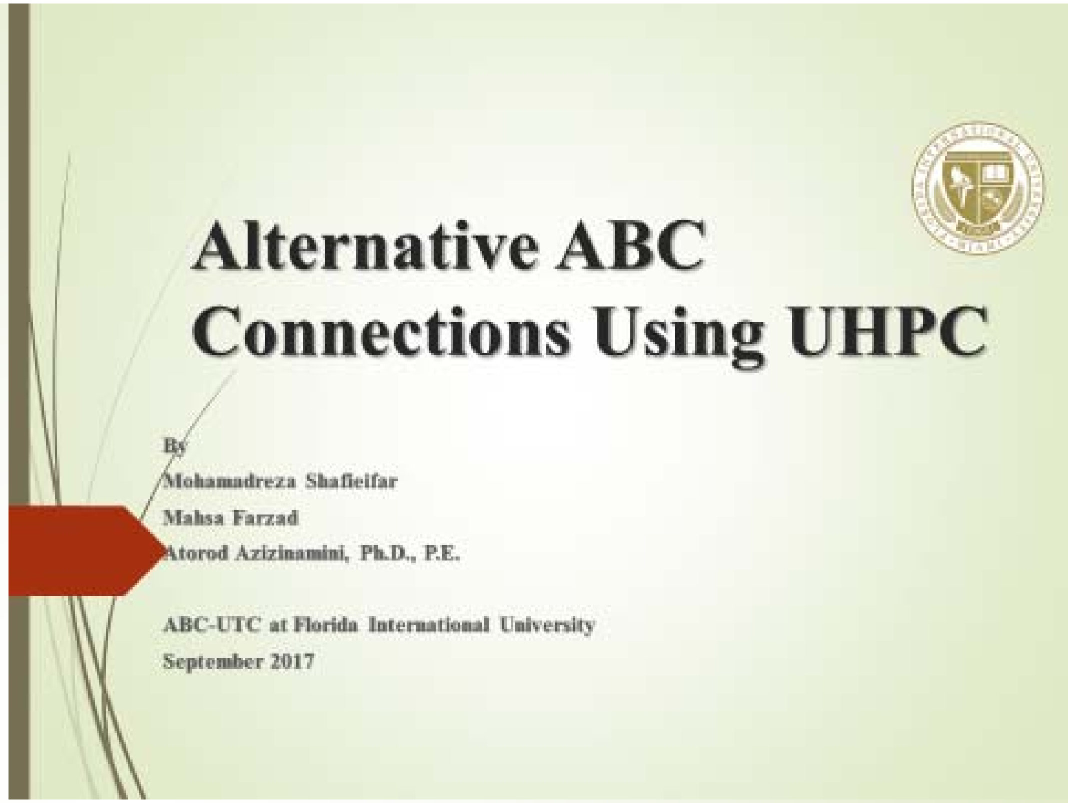
Re-centering Low Damage System → **Construction Sequence**





Recent Innovations in Bridge Design and Construction

ABC-UTC


Alternative ABC Connections Using UHPC

By
Mohamadreza Shafieifar
Mahsa Farzad
Atorod Azizinamini, Ph.D., P.E.

ABC-UTC at Florida International University
September 2017

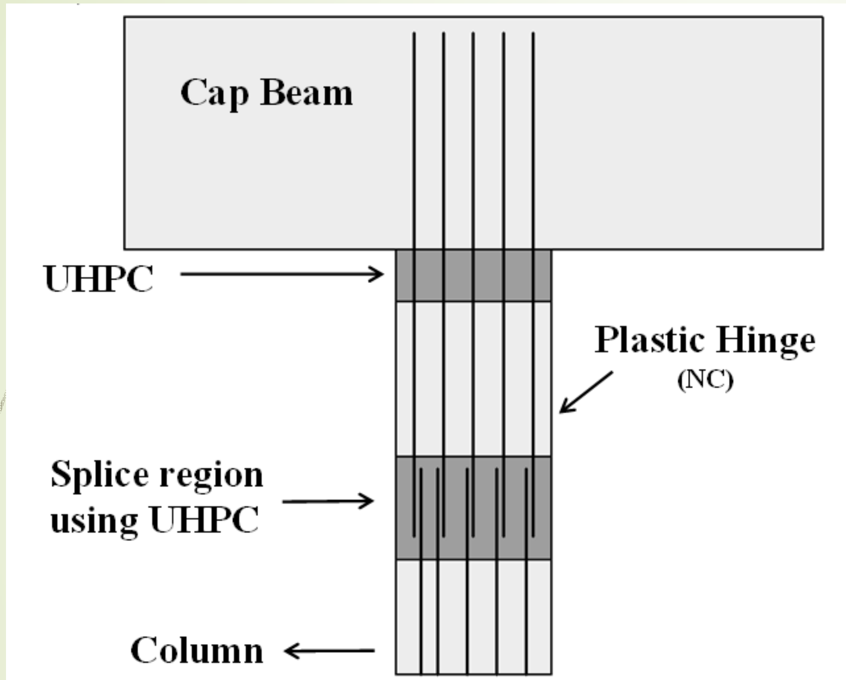
Currently all ABC Connections to connect cap beam to columns uses types of connections that penetrates into the cap beam, creating a very challenging detailing Requirements within the cap beam.



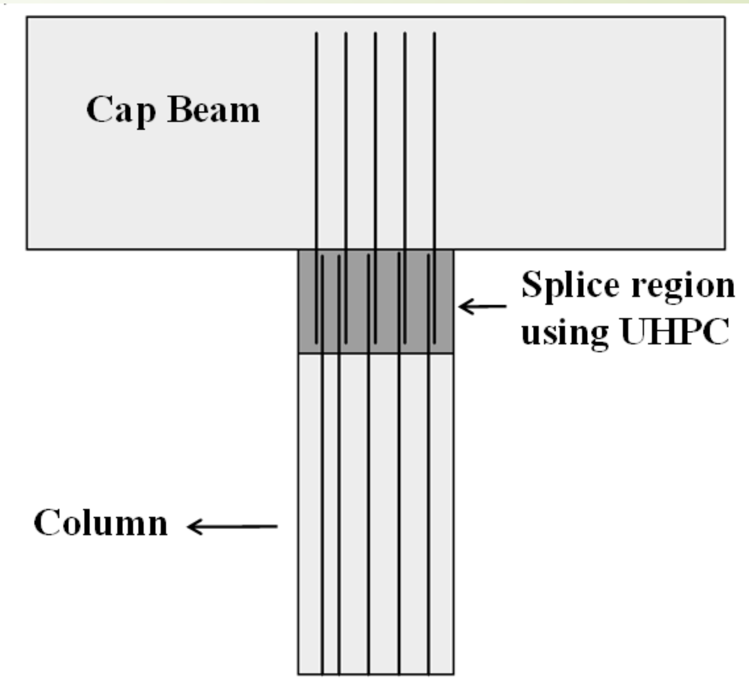
ABC-UTC Research Projects (FIU-ISU-UNR)

RESEARCH DAY- AUGUST 31, 2017 1:00PM - 5:00PM (EST)				
Research Project	**Presentation Topic**	**Presenter**	**Time (EST)**	**University**
		Dr. Armin Mehrabi	**1:00PM-1:10PM**	**FIU**
Alternative ABC Connections Utilizing UHPC	Alternative ABC Connections Utilizing UHPC	Mohamadreza Shafieifar, Ph.D. student	1:10PM - 2:00PM	FIU
	Accelerated Retroffiting of Bridge Elements Subjected to Predominantly Axial Load using UHPC Shell and Associated Design Provisions.	Mahsa Farzad, Ph.D. student		
	Retroffiting Damaged Bridge Elements Using thin UHPC Shell Elemeents	Alireza Valikhani, Ph.D. student		
Extending Application of SDCL to ABC (Phase II Experimental)	Extending Application of SDCL to ABC (Phase II – Experimental)	Amir Sadeghnejad, Ph.D. student	2:00PM-2:20PM	FIU
Estimating Total Cost of Bridge Construction using ABC and Conventional Methods of Construction (Phase II)	Estimating Total Cost of Bridge Construction using ABC and Conventional Methods of Construction (Phase II)	Dr. Mohammed Hadi	2:20PM-2:40PM	FIU
Development of Manual for Enhanced Service Life of ABC Projects	Closure Joint Alternatives for ABC Projects	Azadeh Jaberi Jahromi, Ph.D. student	2:40PM-3:00PM	FIU
Material Design and Structural Configuration of Link Slabs for ABC Applications:	Material Design and Structural Configuration of Link Slabs for ABC Applications:	Dr. Behrouz Shafei	3:00PM-3:20PM	ISU
Investigation of Macro-Defect Free Concrete for ABC including Robotic Construction	Investigation of Macro-Defect Free Concrete for ABC including Robotic Construction	Dr. Katelyn Freeseman & Dr. Brent Phares	3:20PM-3:40PM	ISU
An Integrated Project to Enterprise-Level Decision Making Framework for Prioritization of Accelerated Bridge Construction:	An Integrated Project to Enterprise-Level Decision Making Framework for Prioritization of Accelerated Bridge Construction:	Dr. Alice Alipour & Dr. Doug Gransberg	3:40PM-4:00PM	ISU
Development of Prefabricated Bridge Railings	Development of Prefabricated Bridge Railings	Dr. Sri Sritharan & Dr. Terry Wipf	4:00PM-4:20PM	ISU
Development and Seismic Evaluation of Pier Systems with Pocket Connections and UHPC Columns	Seismic Performance of CFRP Post-Tensioned Precast Square Columns with Resilient Plastic Hinges and Pocket Connection	**Dr. Alieza Mohebbi**	4:20PM-4:40PM	UNR
	Plastic Hinge Damage Comparison of ABC Columns with Different Advanced Materials and Pocket Connections	**Dr. Alieza Mohebbi**		
Shake Table Studies of a Bridge System with ABC Connections	Pretest Nonlinear Dynamic Analysis of A Two-Span ABC Bridge Shake Table Model with Steel Superstructure	Elmira Shoushtari, Ph.D. student	4:40PM-5:00PM	UNR
Wrap up by ABC-UTC Director of Research		**Dr. Armin Mehrabi**	**5:00PM**	**FIU**

Details of the Proposed Connection



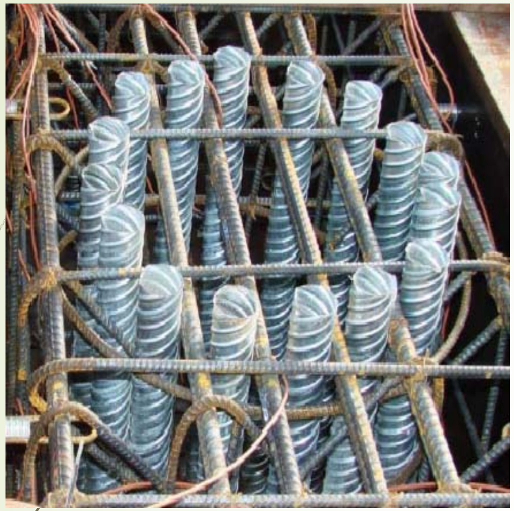
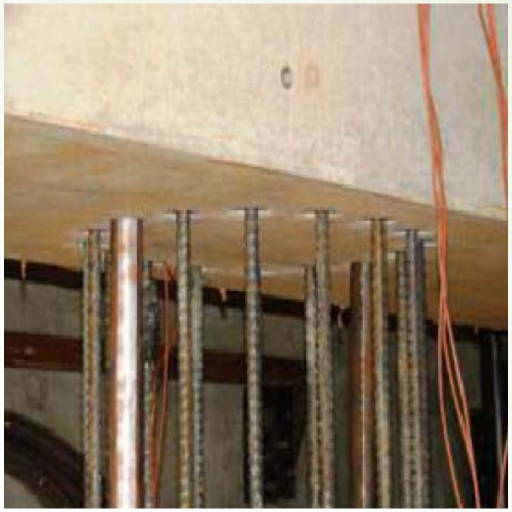
Seismic Detail



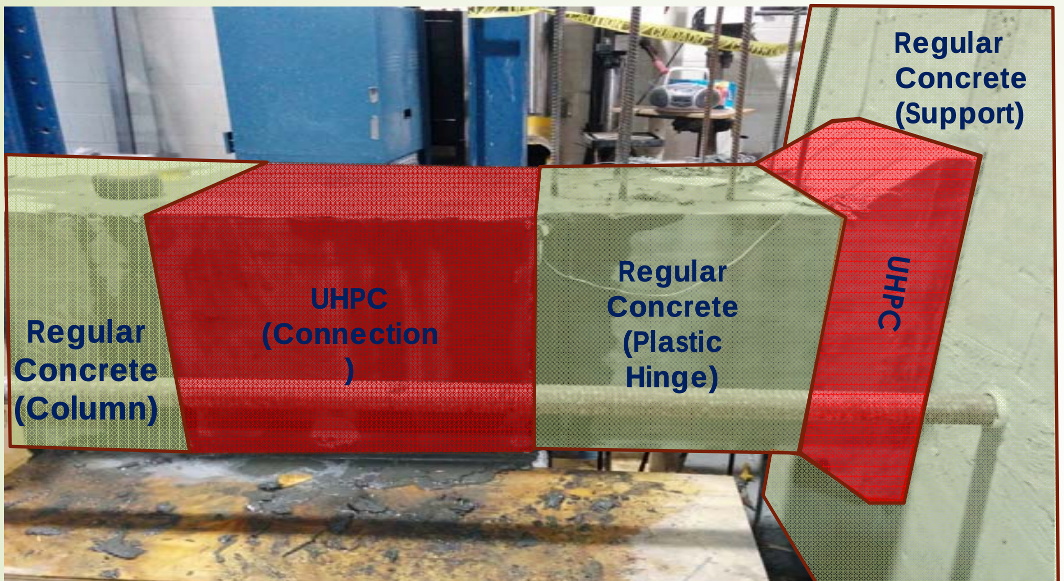
Simplified seismic connection

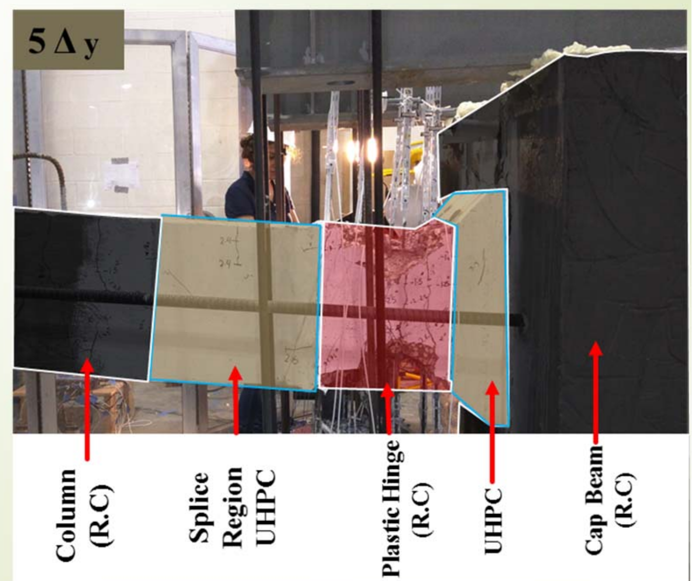
Professor Azizinamini
ABC-UTC at Florida International University

These details works in the laboratory. However, it is very challenging in the field

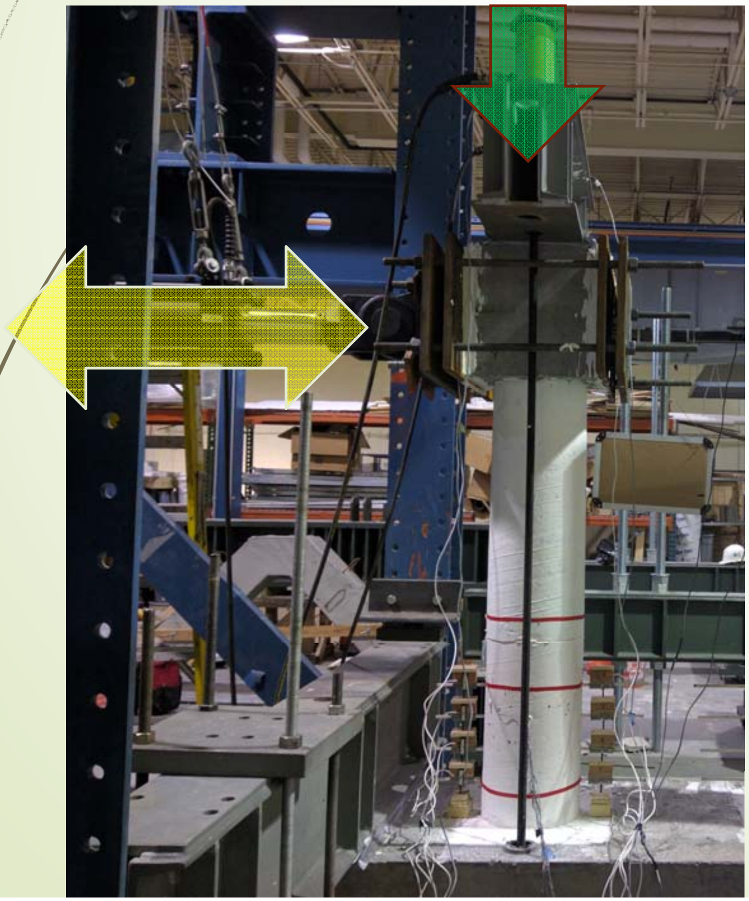

Construction of the Specimen Joining Column – Testing & Results Observations

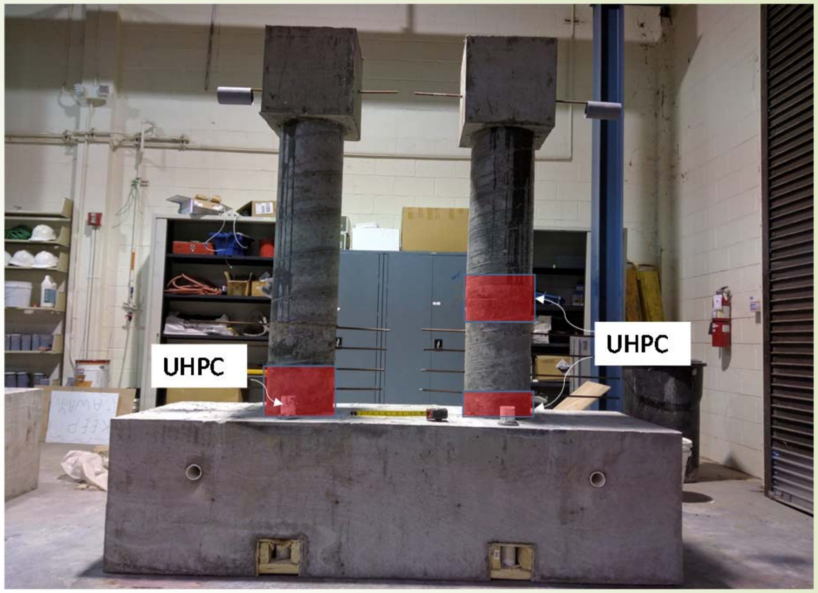


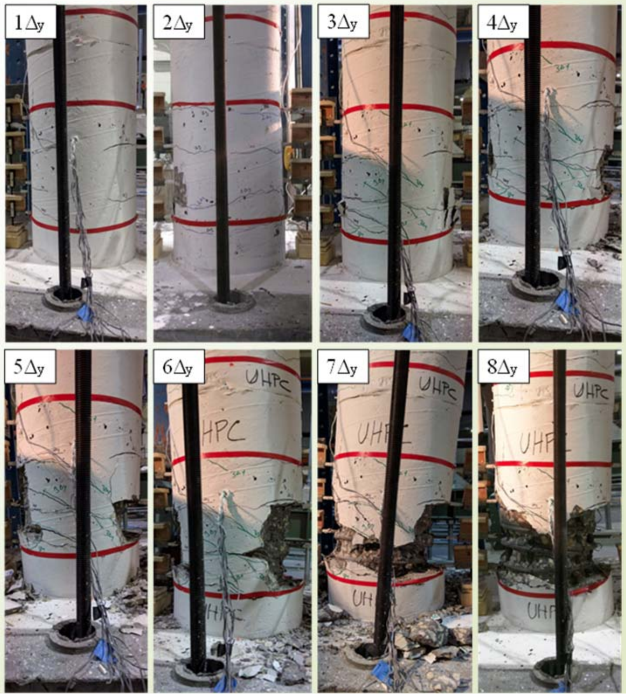


Construction and Testing the Specimen

Loading and Supports:
Axial Load=56 Kip (10% Pu)



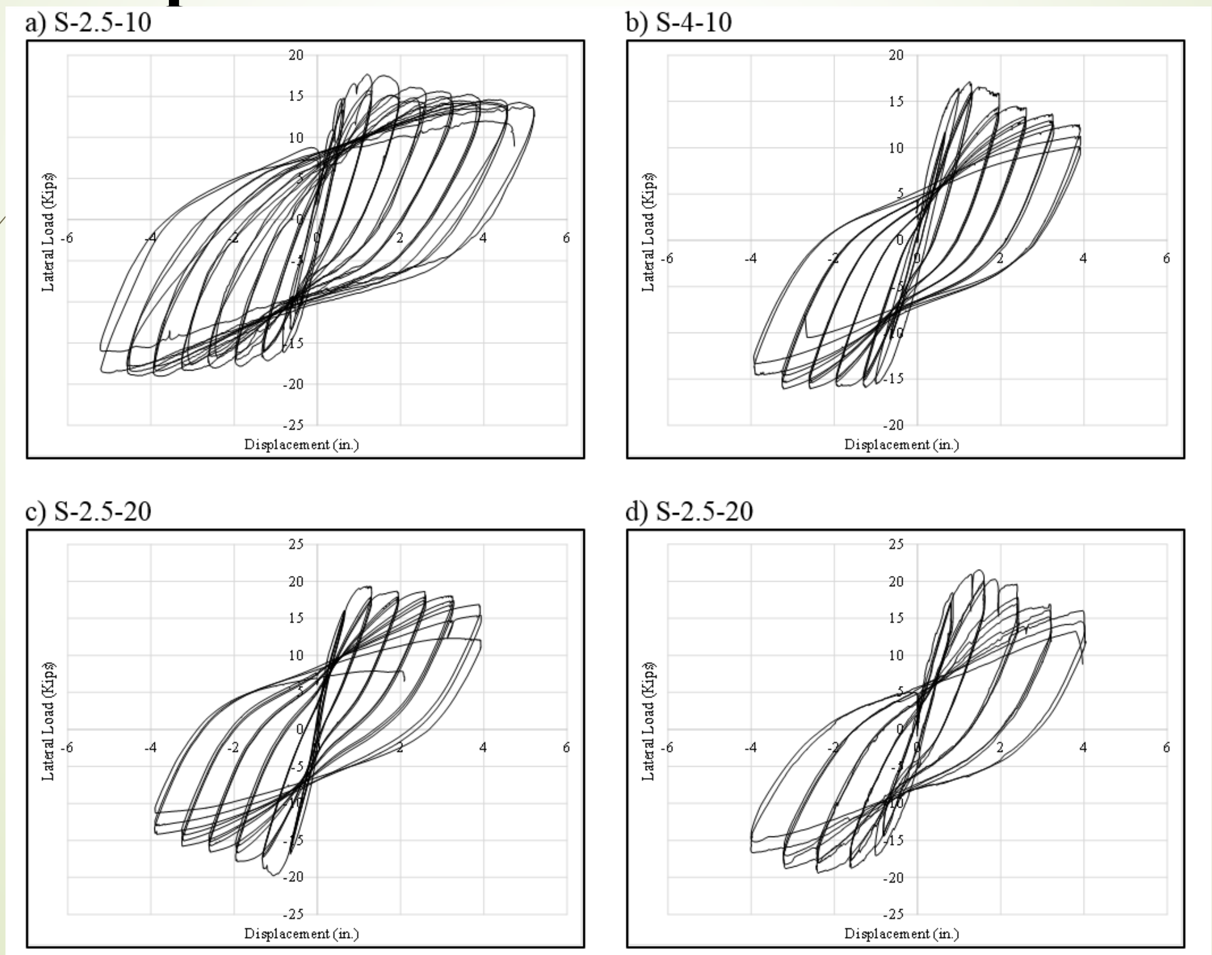




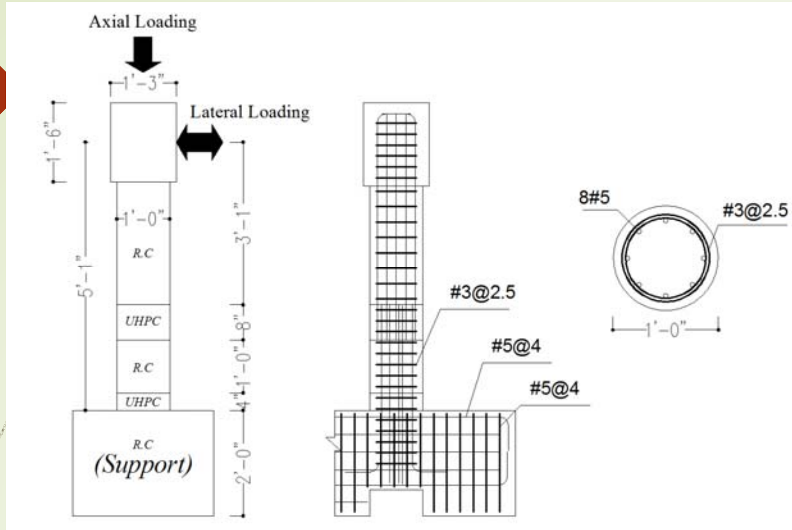
Test Results

Specimen ID	Maximum drift	Displacement ductility
S-2.5-10	8.5 %	8
S-4-10	5.3 %	5
S-2.5-20	6.4%	6
NS-2.5-10	6.5%	5

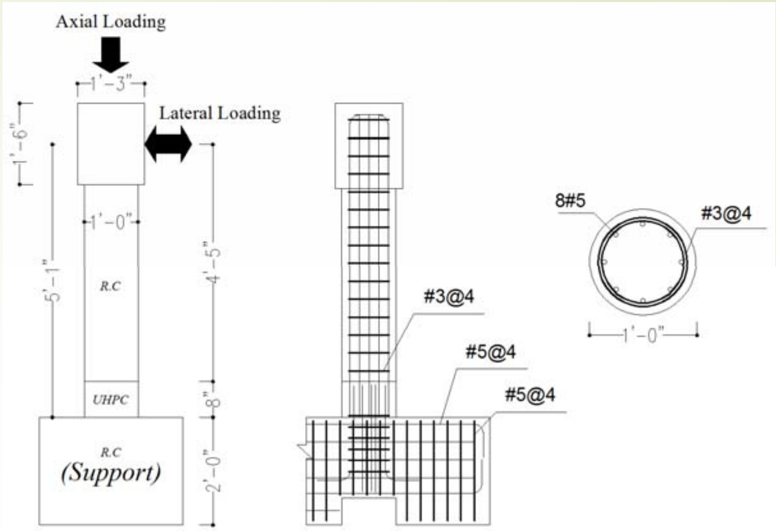
Load-Displacement



Test Specimen Dimension (Parametric Study)



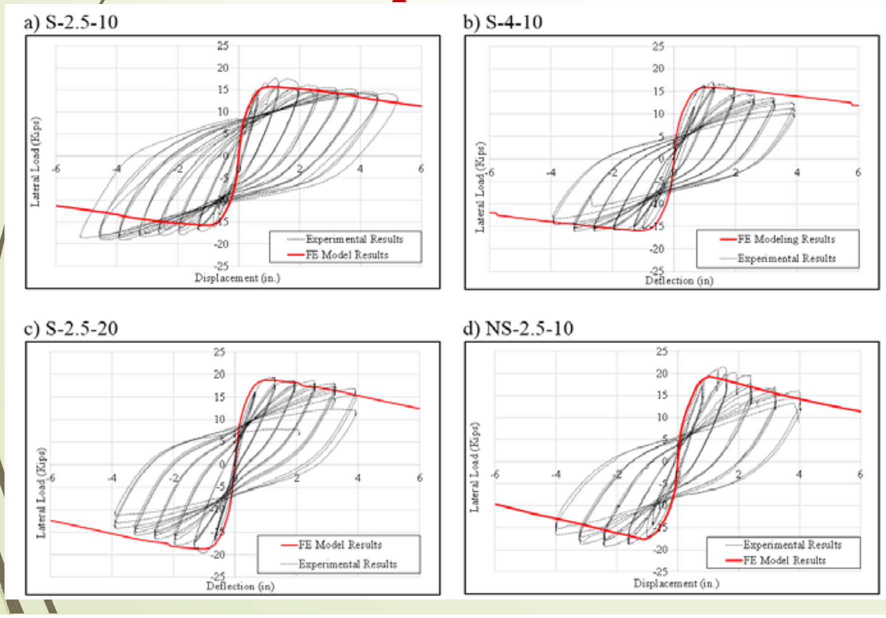
Seismic Detail



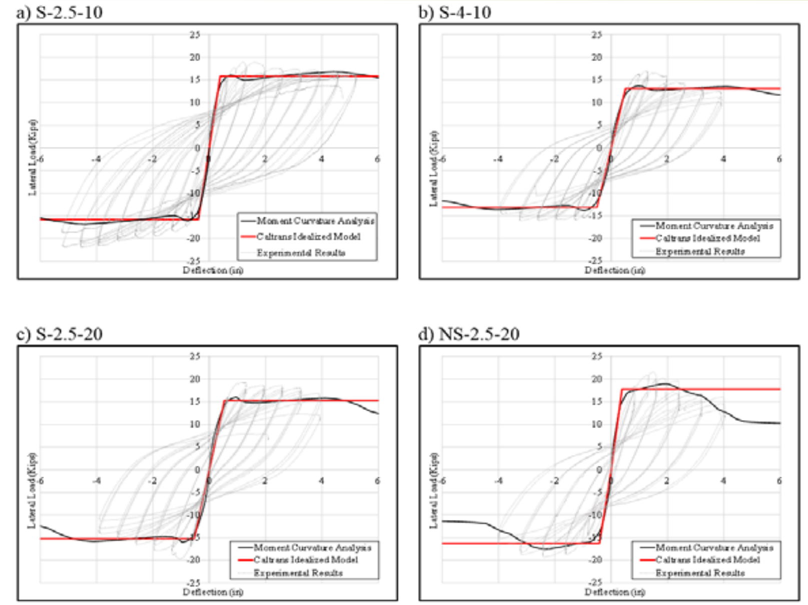
Simplified Seismic Detail

Numerical Analysis:

Load-Displacement

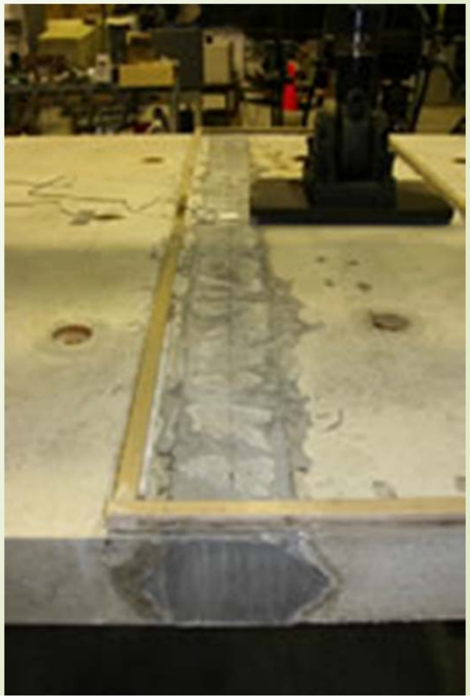


Moment –Curvature



UHPC Advantages

- Superior Mechanical Strength Results In Smaller Sections
- Greater Ductility And Energy Absorption During Seismic Events
- Dense Microstructure And Discontinuous Pore Structure Provide
- Protection Against Corrosion
- Excellent Chloride Penetration Resistance And Low Water Absorption
- Excellent Freeze-thaw Durability

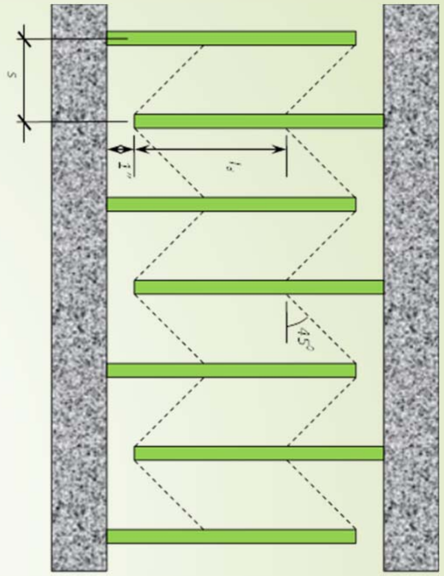


UHPC - Innovative Materials

- **Steel Fibers**: NYCON-SF - I
  - Length: 0.5 in.
  - Diameter: 0.008 in.
  - Aspect ratio = 65
  - Tensile strength: 400 ksi
  - Flexural strength: 29.000 ksi
  - High Alkali
  - Corrosion resistance

Research Projects: WSU & UW

- Develop a UHPC connection between Deck Bulb Tees, using straight bars.
- Develop local UHPC mixes
- Develop and test joint design methodology
- Joint width/bar splice length.
- Bar spacing (splice offset).
- Bond/pullout and splice tests.
- Develop Design and Detailing



WSU PI: Professor Pizhong Qiao
UW PI: Professor John Stanton

WSU Test Set ups

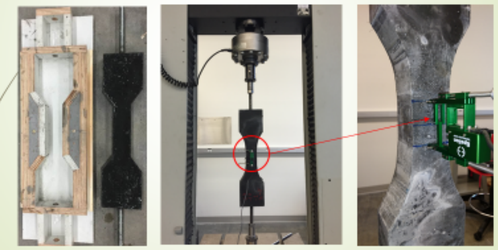
Workability Test

- Test method: Standard Test Method for Flow of Hydraulic Cement Mortar (ASTM C 1437)

Vibrate 25 times in 15 seconds

Direct Tension Test – New ASTM STD

- Direct Tension Test (DTT) (in progress)
  - The cross-section of 2" x 2" and total length of 18" dog-bone shaped specimen



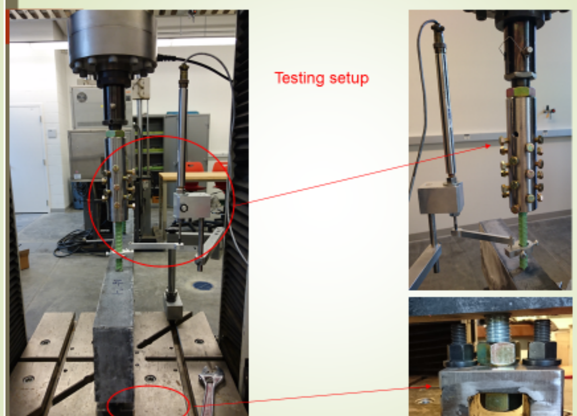
Dimensions of Specimen for DTT | DTT Setup | Extensometer Setup

Flexural Strength (Modulus of Rupture) Test

- Flexural Strength (Modulus of Rupture)
  - 3" x 4" x 16" Prism Specimen (ASTM C78)

Casting of 3" x 4" x 16" prism flexure specimens | Flexural testing of 3" x 4" x 16" in. specimen (span = 12")

Pull-out Test

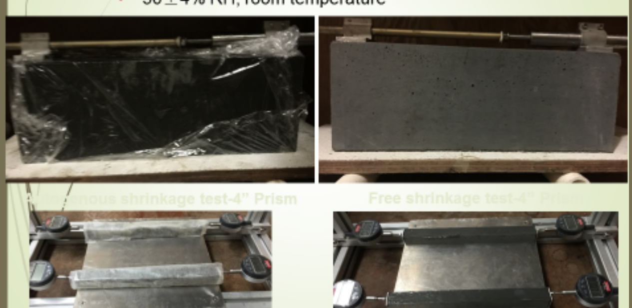


Splitting Tensile Strength Test

- Splitting Tensile Strength
  - 6" x 12" Cylinder (ASTM C496)

Shrinkage Test

- Shrinkage (Both Autogenous and Free shrinkage)
  - 4"x 4" x 11.25" prism specimen (ASTM C157)
  - 1"x 1" x 11.25" prism specimen (ASTM C157)
  - 50±4% RH, room temperature



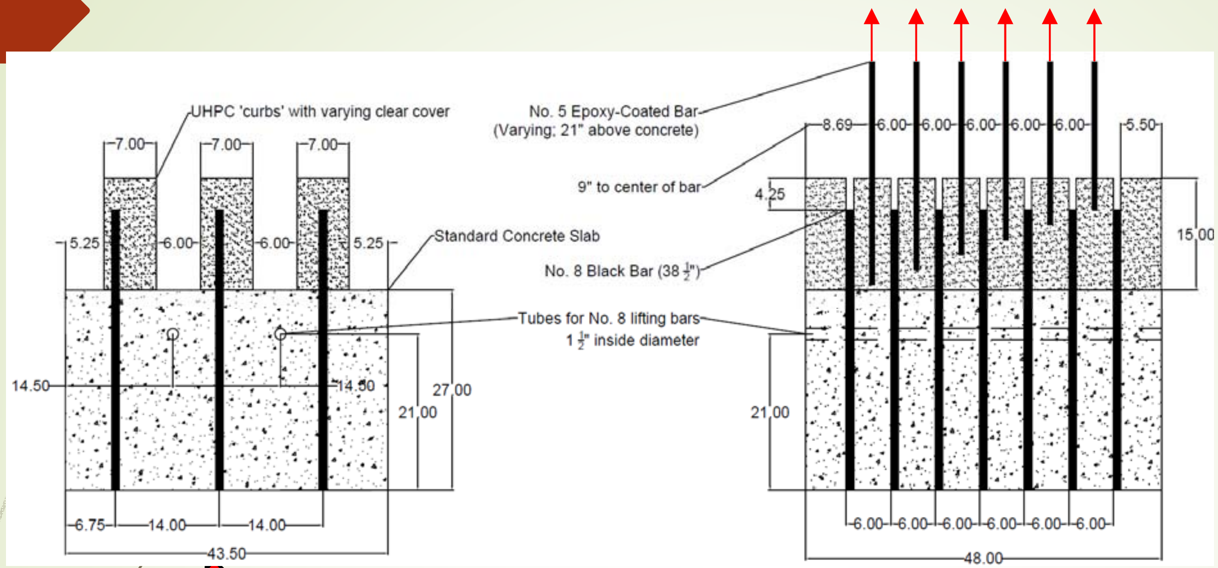
Modulus of Elasticity (MOE)

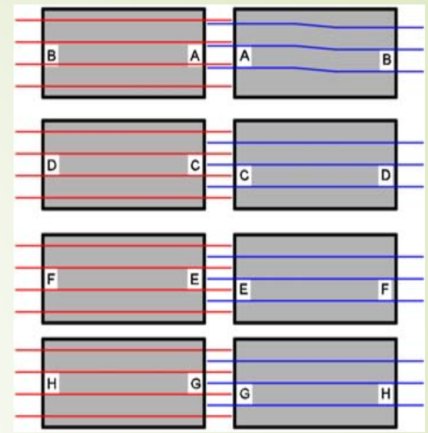
- Modulus of Elasticity (MOE)
  - 6" x 12" Cylinder (ASTM C469)

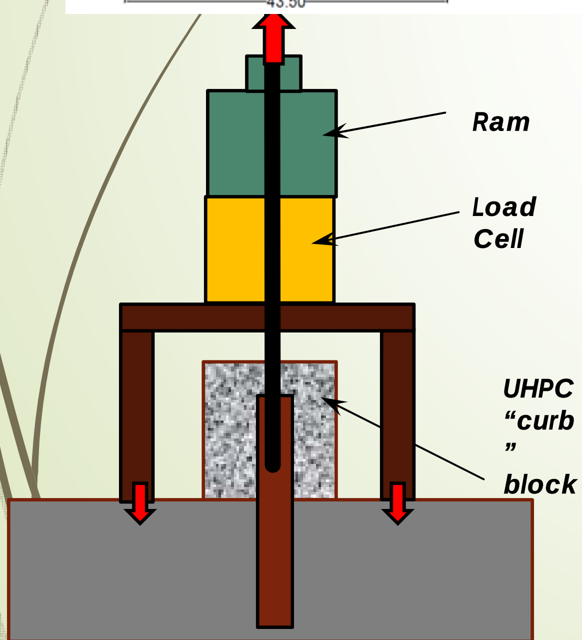
Compressive Strength Tests

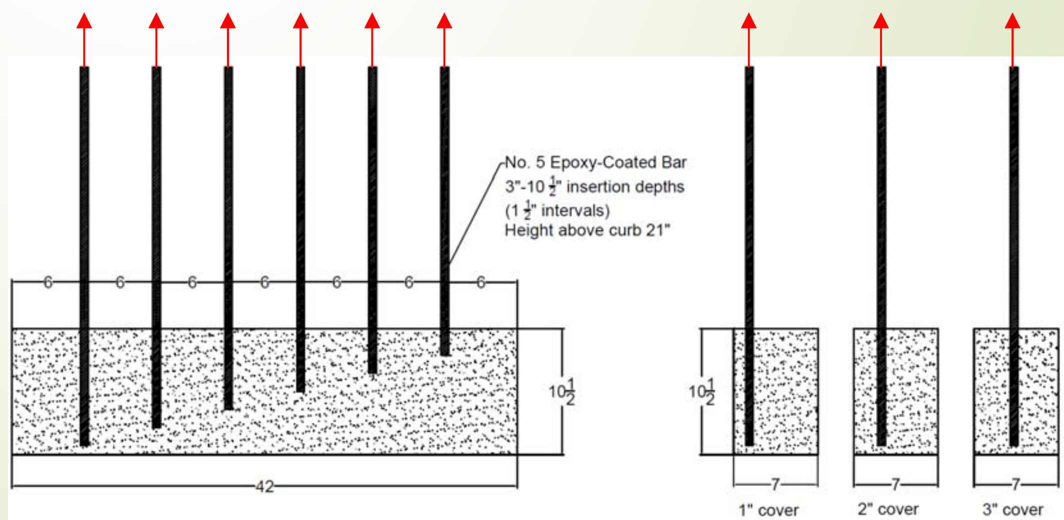
- Compressive Strength
  - 2" Cubes and 4" Cubes (ASTM C109)

UW Test Setup



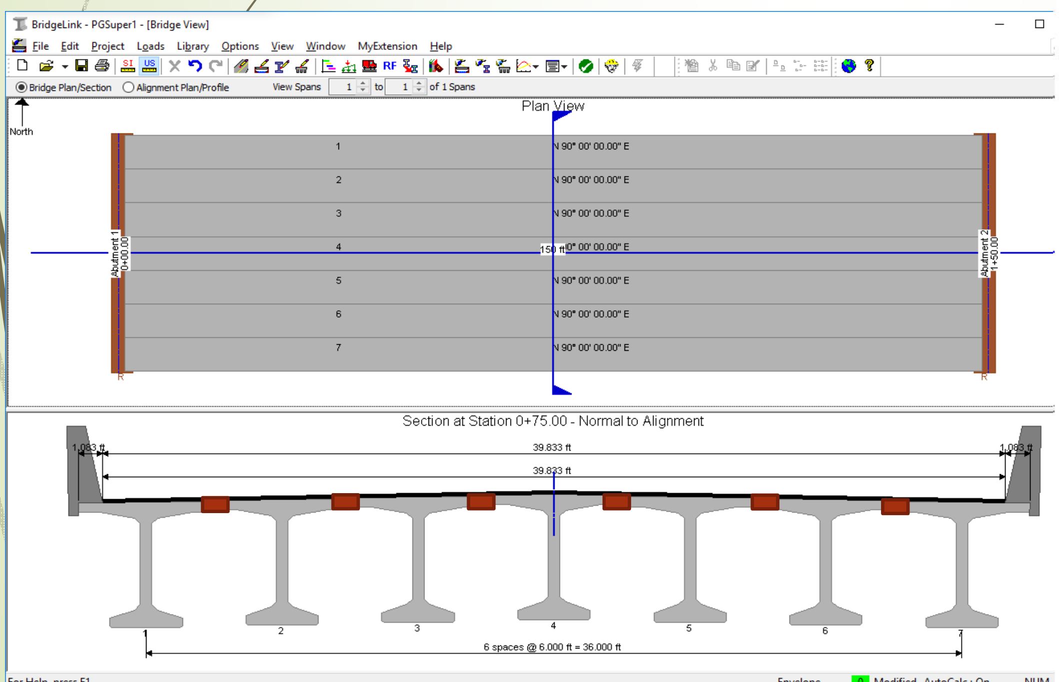






Implementation: WF Deck Girders with UHPC Connections

- Develop Span Capability charts for Wide Flange Deck Girders with UHPC Connections.
  - Normal Weight and Light weight Concretes
- Develop STD Drawings/Details
- Develop Design Examples

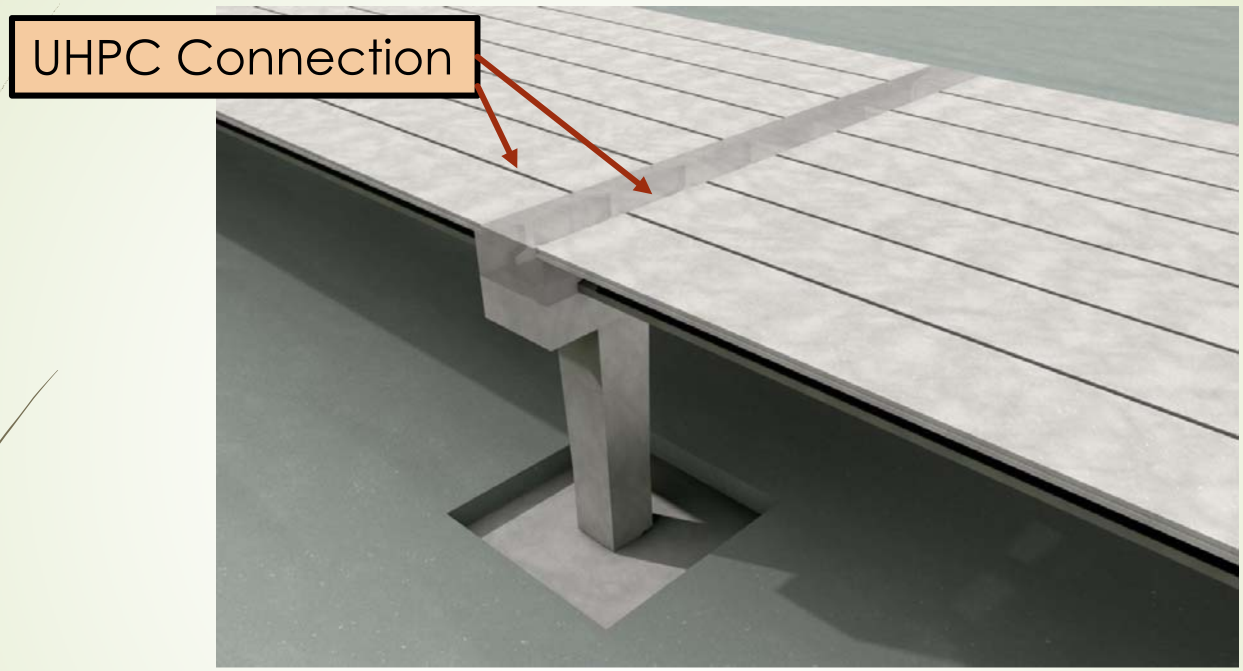


Appendix 5.6-A1-5 ***Span Capability of WF Deck Girders***

Girder Type	Girder Spacing (ft)	CL Bearing to CL Bearing (ft)	Shipping Weight (kips)
WF39DG	5	115	122
	6	110	126
	7	100	123
	8	100	131
WF45DG	5	130	143
	6	125	148
	7	115	146
	8	105	142
WF53DG	5	145	167
	6	140	173
	7	130	172
	8	125	176
WF61DG	5	160	193
	6	155	200
	7	145	200
	8	135	198
WF69DG	5	170	215
	6	165	223
	7	155	222
	8	150	228
WF77DG	5	185	244
	6	180	253
	7	175	261
	8	165	260
WF86DG	5	195	270
	6	180	264
	7	170	264
	8	160	262
WF98DG	5	180	265
	6	170	265
	7	160	263
	8	155	268
WF103DG	5	175	264
	6	165	263
	7	160	269
	8	150	264

System Performance of UHPC Connected Bridge

WF-DG with UHPC Connection
Longitudinal and Transverse



- System test: Multiple girders to verify moment continuity at the intermediate pier and longitudinal joints between girders.
- Different connection details with different UHPC mixes.
- Service loads, cyclical testing of at least two million cycles, and ultimate strength.

Concluding Remarks:

1. Seismic performance could be achieved with using Innovative materials, design and construction methods.
2. Connection testing of innovative systems have shown satisfactory results meeting the performance requirements.
3. Ductility depends strongly on details. Combine concepts and details to suit particular performance.
4. All of the major connection types (Socket, Pocket, Grouted Sleeves or Ducts, Mechanical Connectors) have been tested under cyclic loading
5. Need for PBSD to recognize innovations in seismic design and performance

Thank You:
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Questions?