PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

2019 ANNUAL MEETING

JANUARY 17-18, 2019 LOS ANGELES, CA

SEISMIC RESILIENCE 25 YEARS AFTER NORTHRIDGE: ACCOMPLISHMENTS AND CHALLENGES

UC BERKELEY • CALTECH • OSU • STANFORD • UC DAVIS • UC IRVINE • UC LOS ANGELES • UC SAN DIEGO • UNR • USC • U WASHINGTON

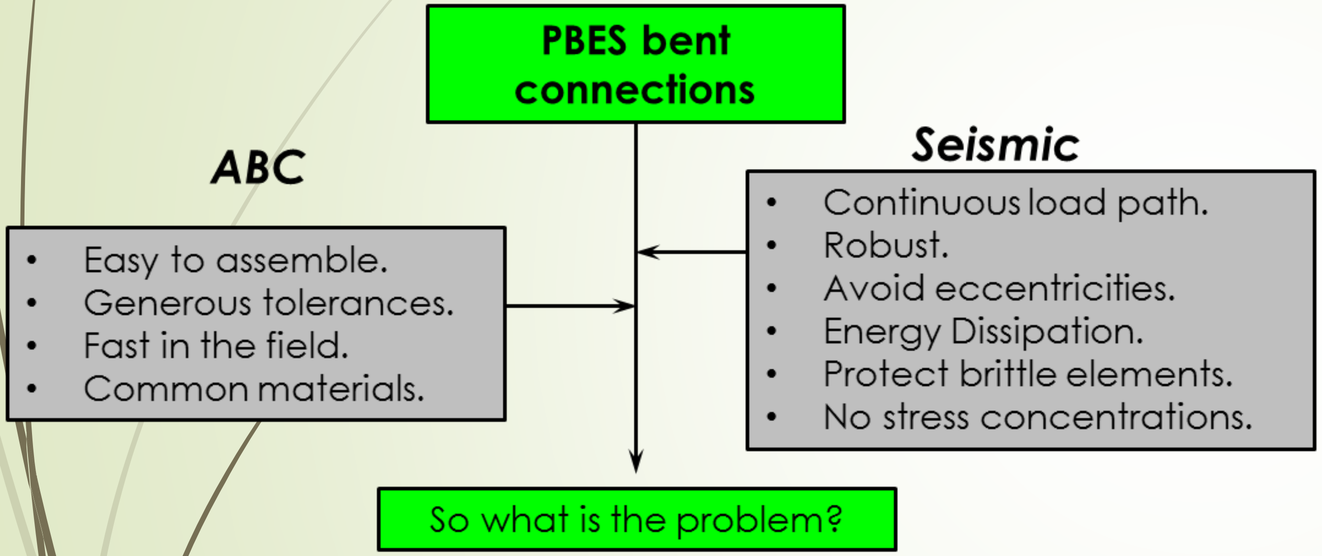
Accelerated Bridge Construction in Pacific Northwest Seismic Regions

Outlines:

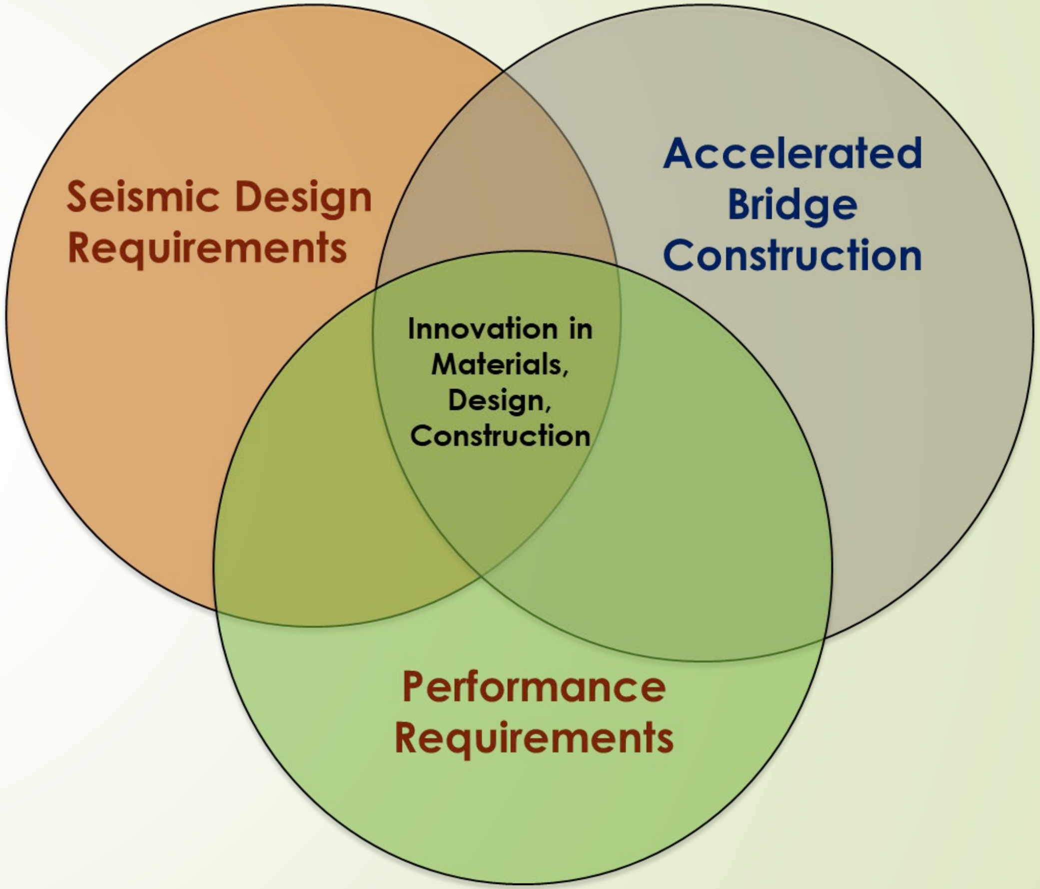
- ✓ Accelerated Bridge Construction in Washington
- ✓ Fully Precast Bridges – HFL
- ✓ UHPC Pier Connections
- ✓ Superelastic Materials - IBRD
- ✓ Prestressed Columns with Self Centering Capability

Bijan Khaleghi, PhD, PE, SE
State Bridge Design Engineer
WSDOT - Bridge & Structures Office

Accelerated Bridge Construction & Seismic Challenges

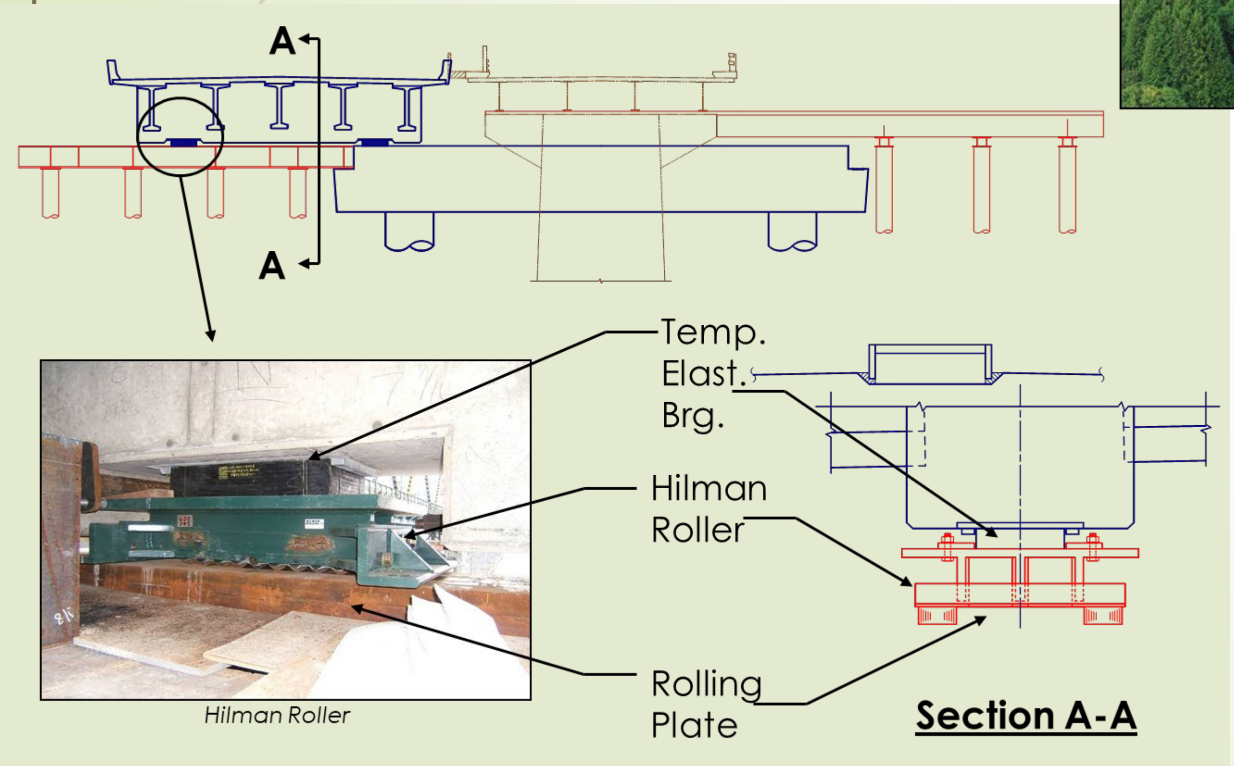


Requirements for ABC and seismic often conflicting.
Need approaches that solve both problems together.



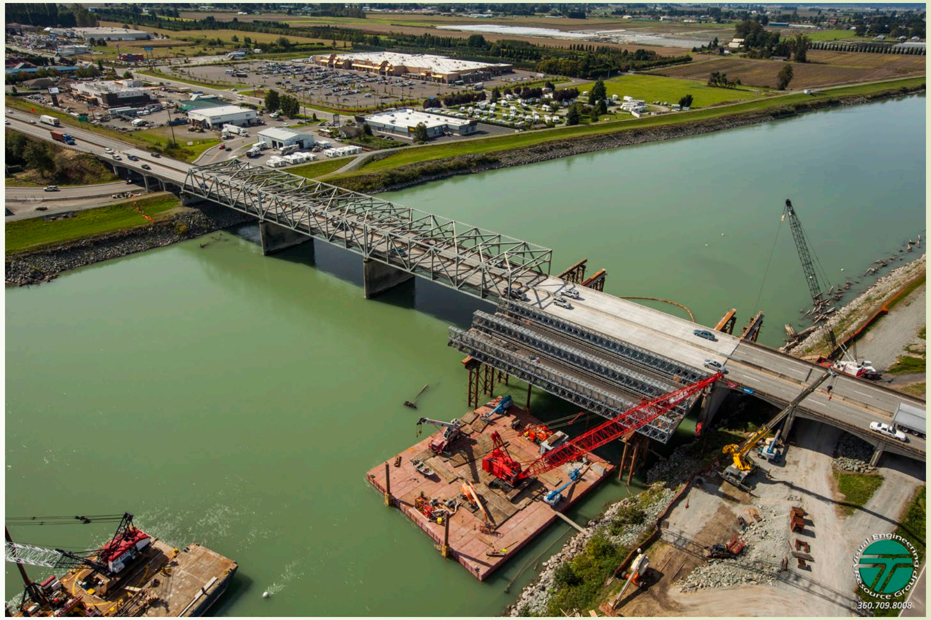
Examples of WSDOT ABC Projects

Hood Canal Approach Bridge Construction



ABC - Bridge Lateral Slide: Night Closure

7 pm Saturday September 14th



2 pm Sunday September 15th

Bridge Move Summary:

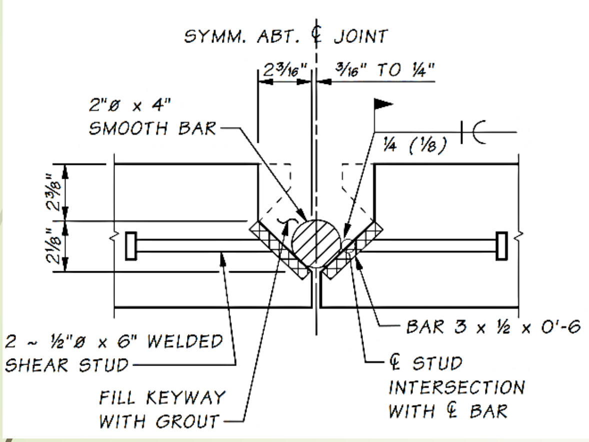
1. Temporary Span out (25 min.)
2. Permanent Span in (45 min.)
3. Deck Lowering (30 min.)

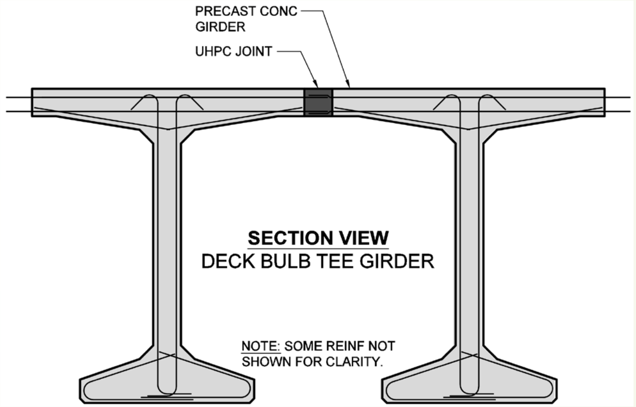
Skagit River Bridge Switchover_mpeg2video.mpg

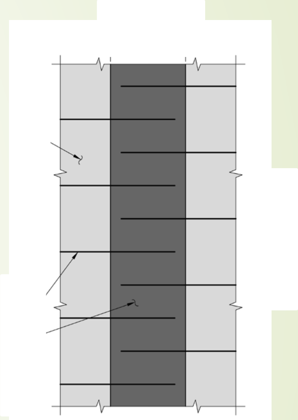
http://wwwi.wsdot.wa.gov/eesc/bridge/ABC/

UHPC Connection for DBT Bridges - ABC

- Existing bridges constructed via this method have shown poor performance from the welded bars.
- Proposed Solution: Eliminate the welds and use UHPC to create the longitudinal joint.



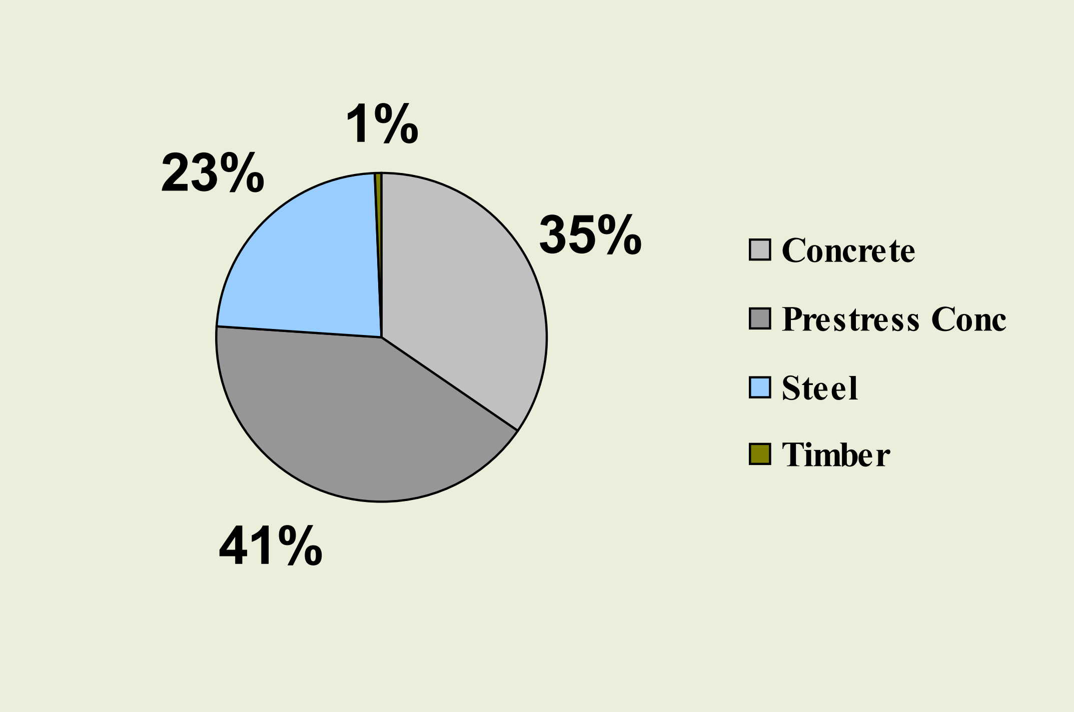


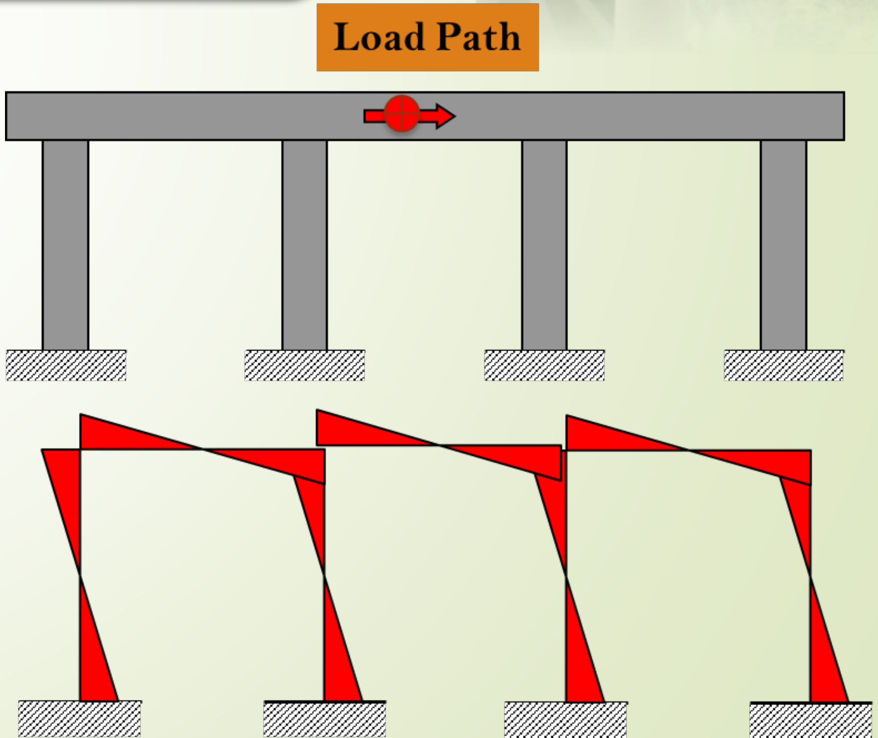


SCOPE: Develop a new, inexpensive UHPC mix using local materials, test its structural performance, and specify a joint width.

Bridge Substructure & Seismic Design Requirements

Typical WSDOT Precast prestressed girder bridge with dropped bent cap

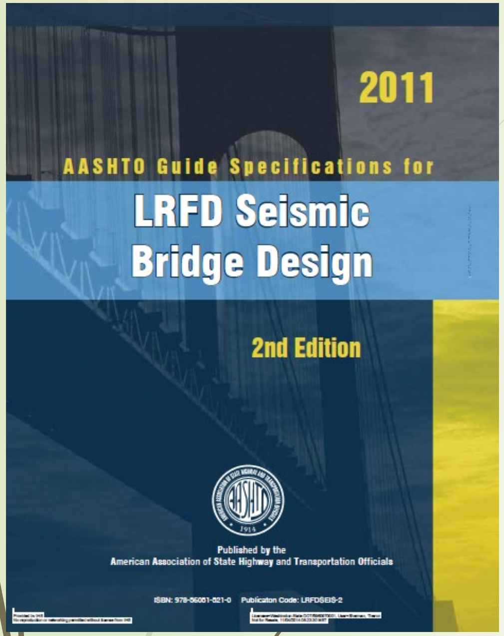


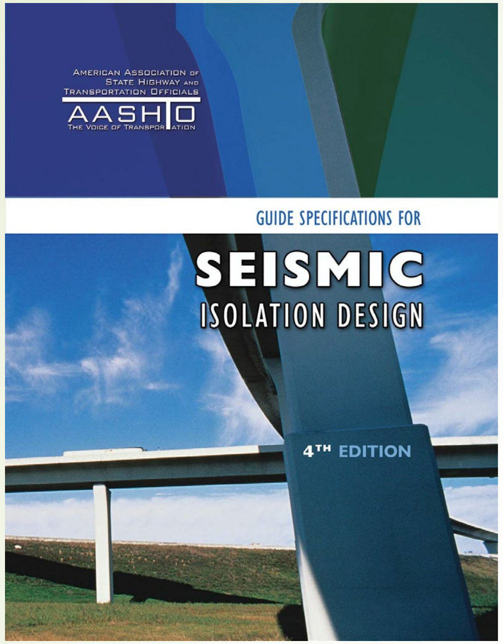


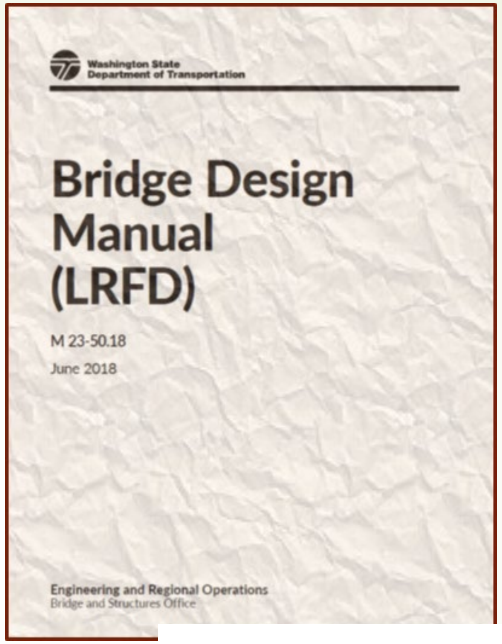
Connections need to be:

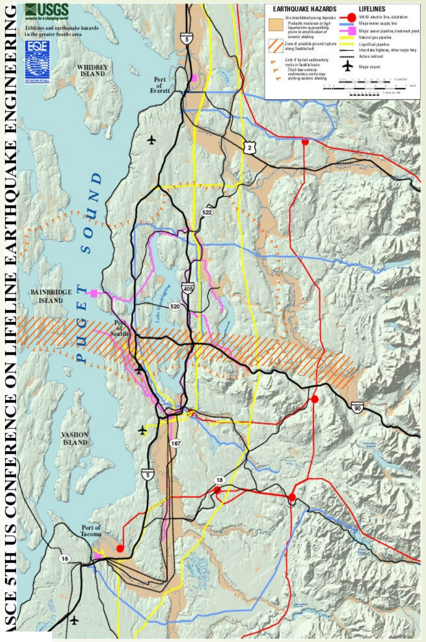
- Constructible
- Seismic Resilient – Emulative
- Long term Performance & Longevity

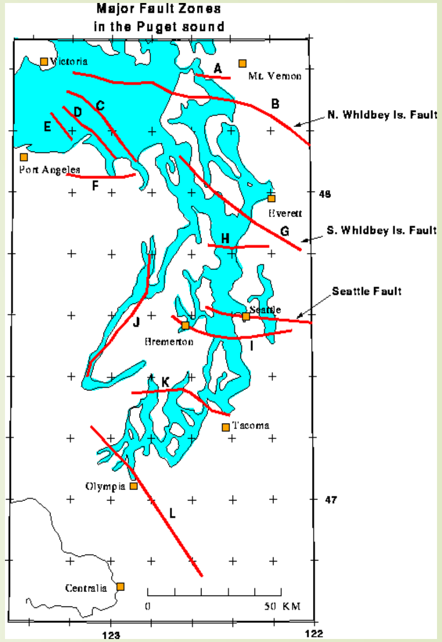
Seismic Design Specifications

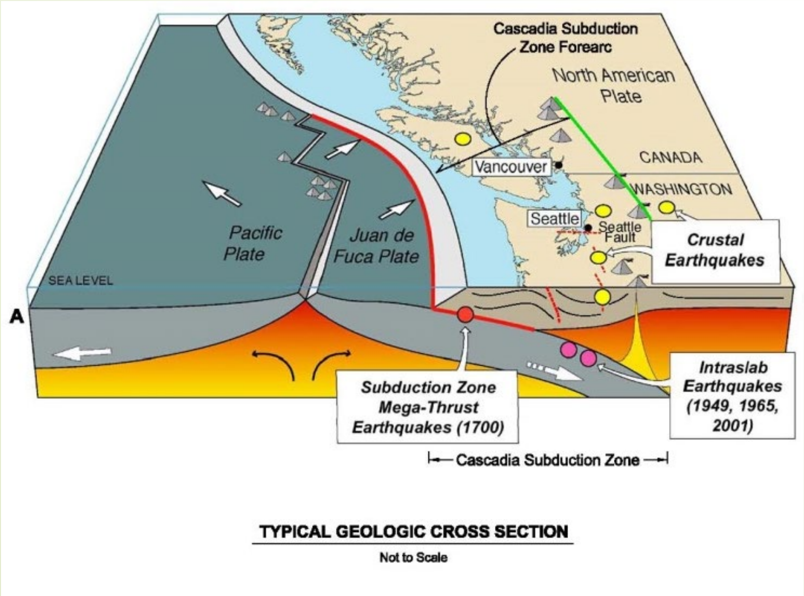


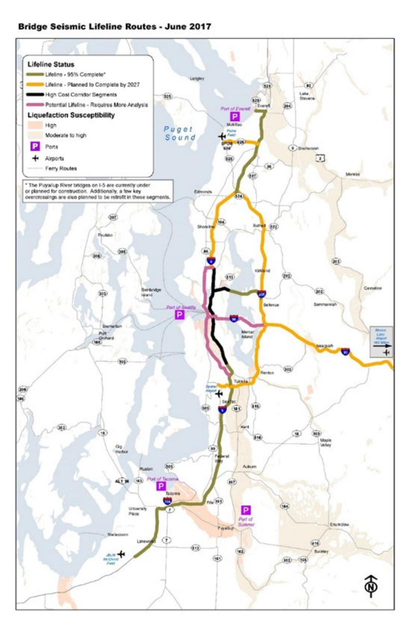






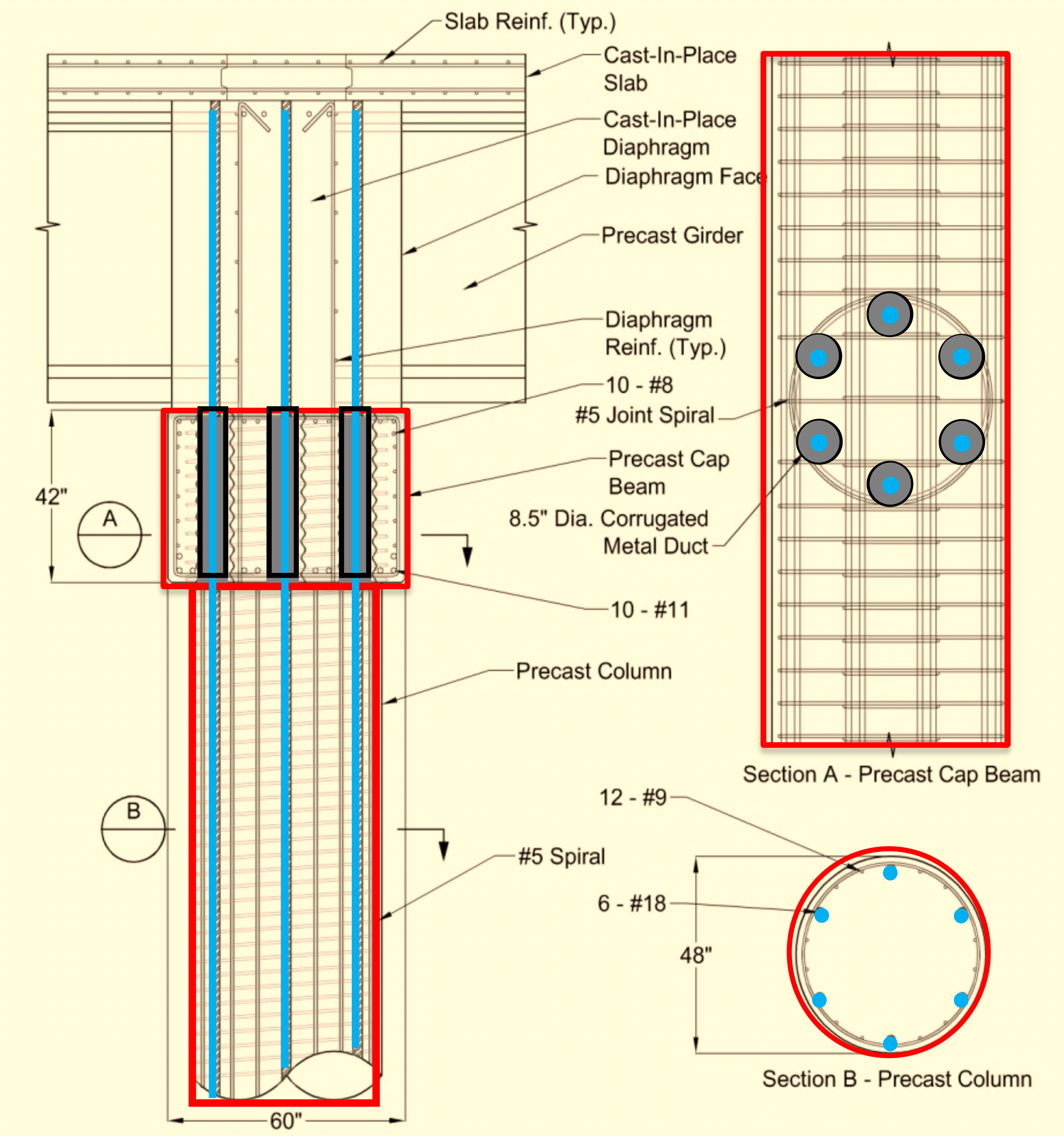


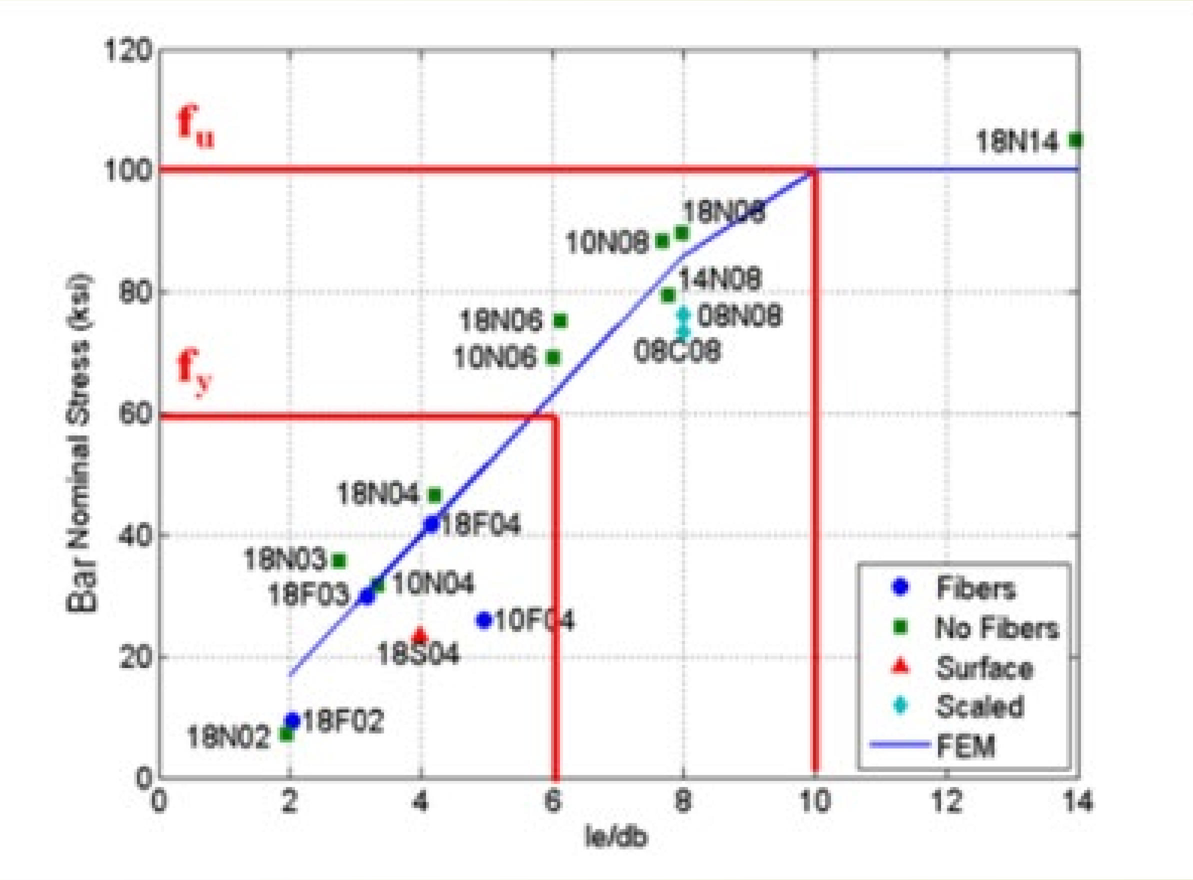




- 2014 Seismic Hazard Maps and Site Coefficients
- FEE and SEE Two level Seismic Design
- Grade 80 A706 Rebar

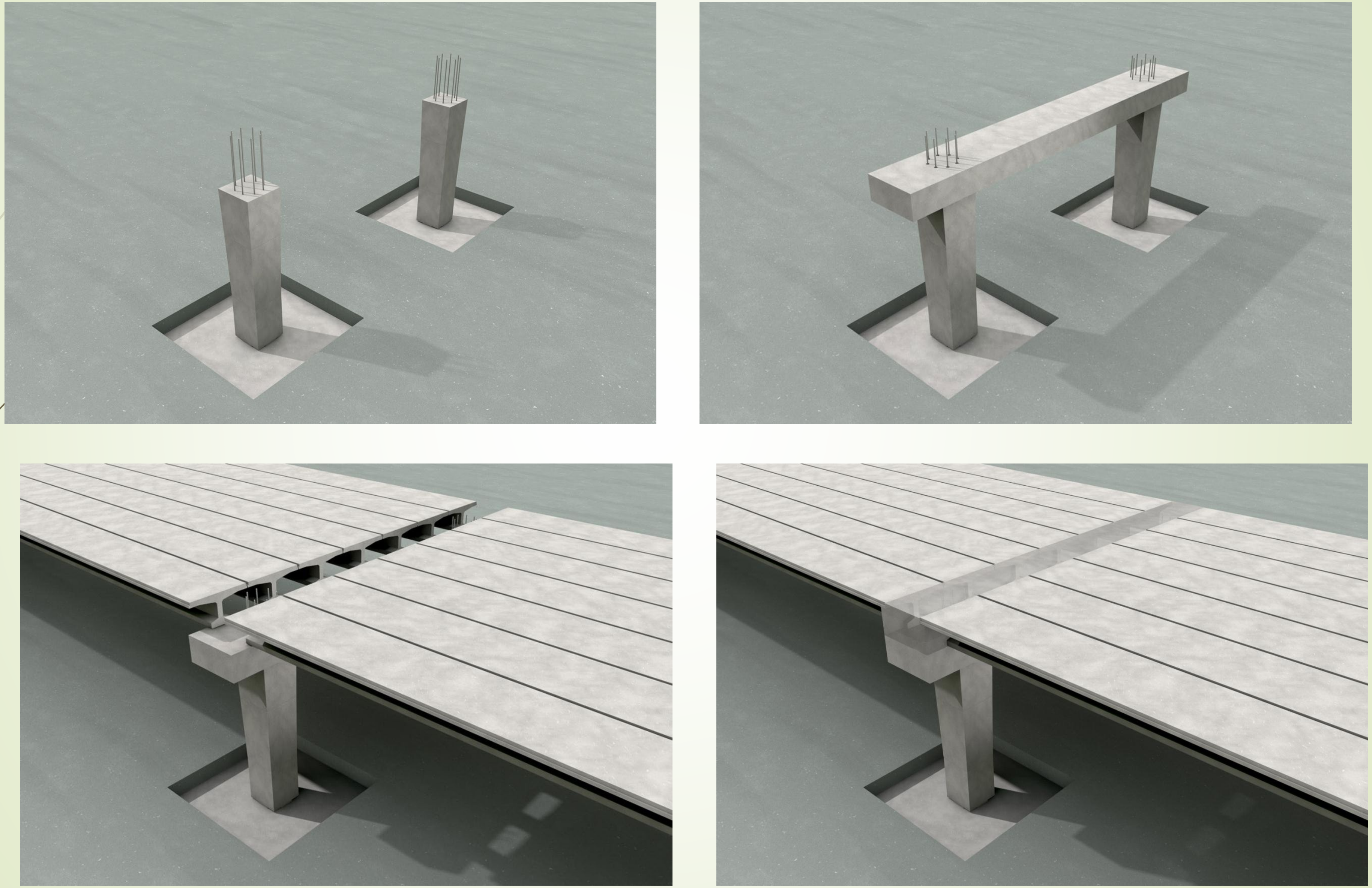
Large-Bar Connection - UW



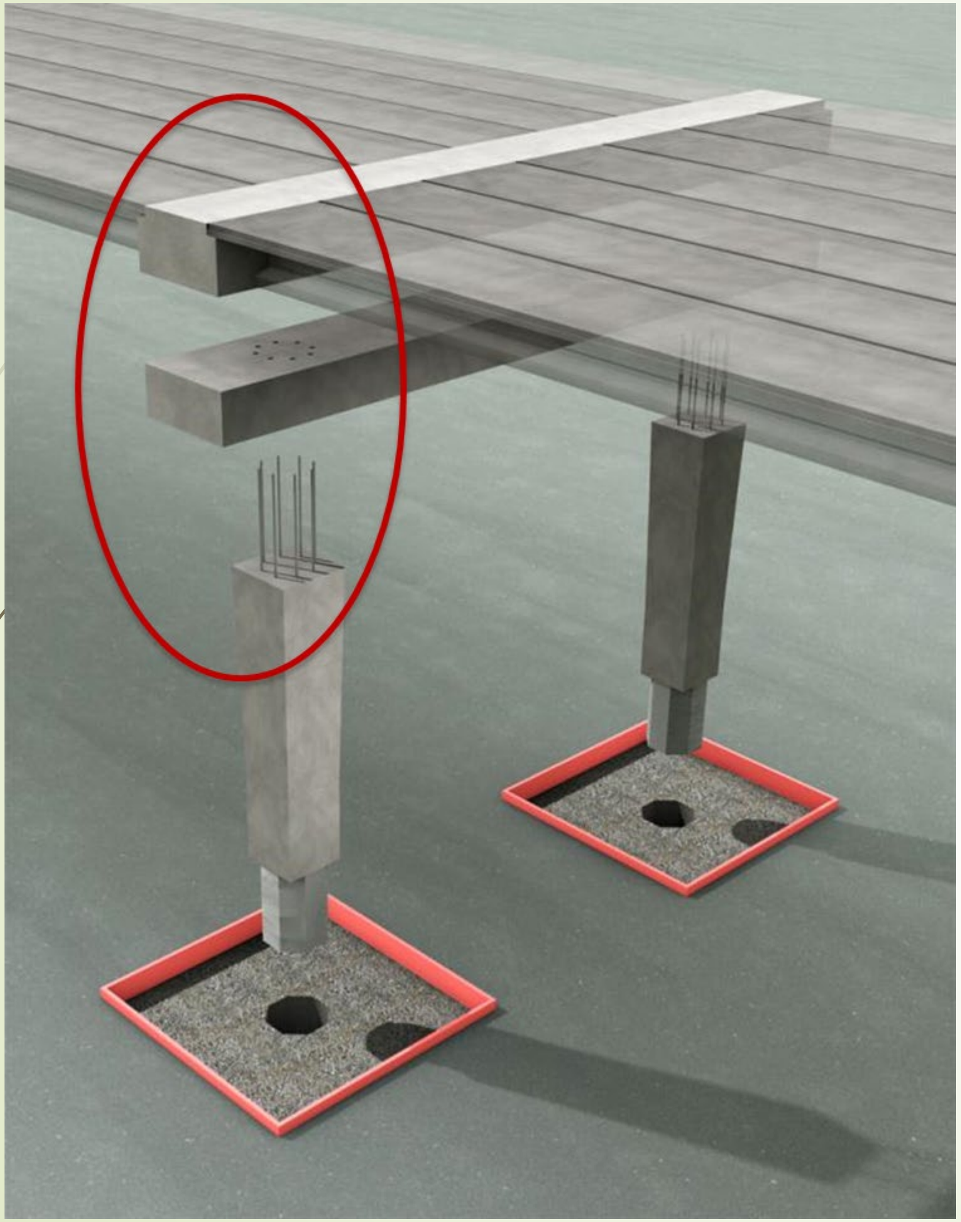


- Member socket connection at base
- Large, bars at precast cap connection
- Two-stage cap
- Upper stage CIP
- Girders integral with combined lower and upper stages of cap

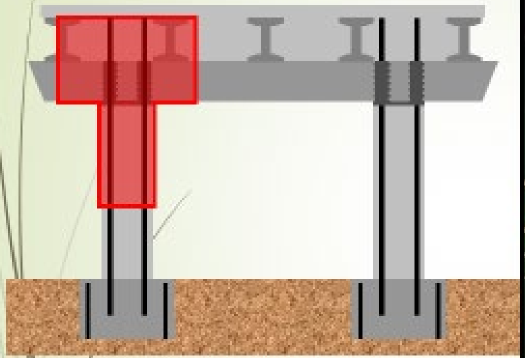
Precast Bridge System in High Seismic Regions - HFL

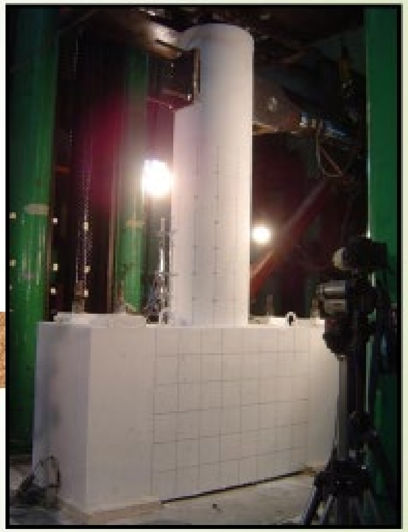


Column-to-Cap Connection

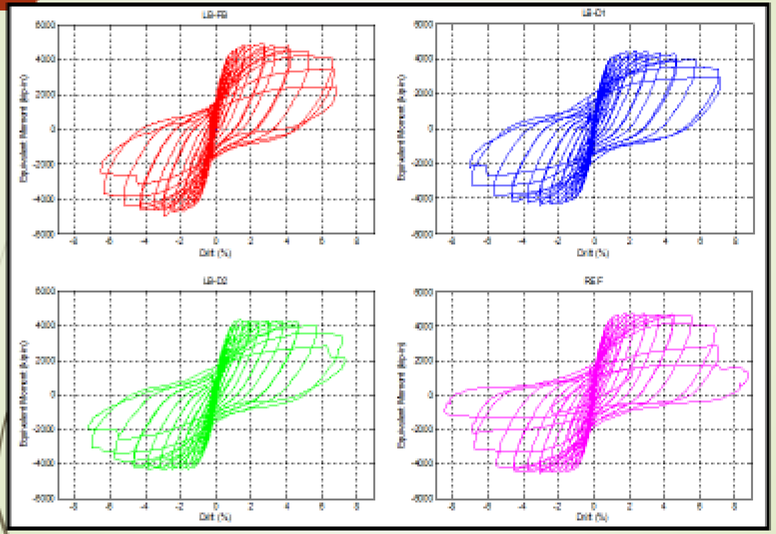


Connection Tests (42% Scale)





Moment vs. Drift

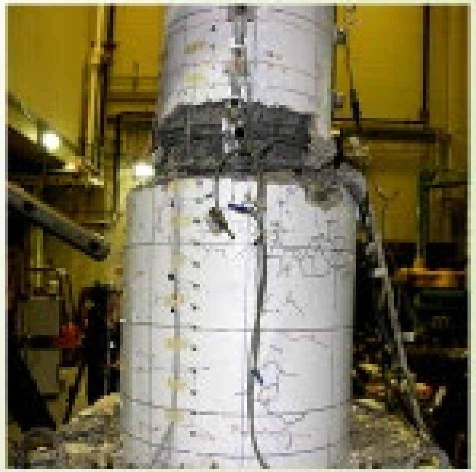


Same response for precast and CIP

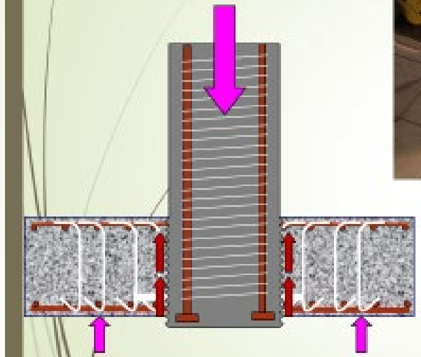
Column-to-Spread Footing and Shaft Connection Tests

Column-Shaft Tie Reinforcement

		DS-1	DS-2	DS-3
Column Diameter		20 in.	20 in.	20 in.
Column Reinforcement Ratio		1.0 %	1.0 %	1.6 %
Shaft Diameter		30 in.	30 in.	26 in.
Lateral Reinforcement Efficiency Factor [k]	Top 1 ft.	0.75	0.375	1.30
	Upper Half	0.50	0.25	1.00
	Lower Half	0.50	0.25	1.00
Failure		Column	Shaft	Column



Spread Footing Connection

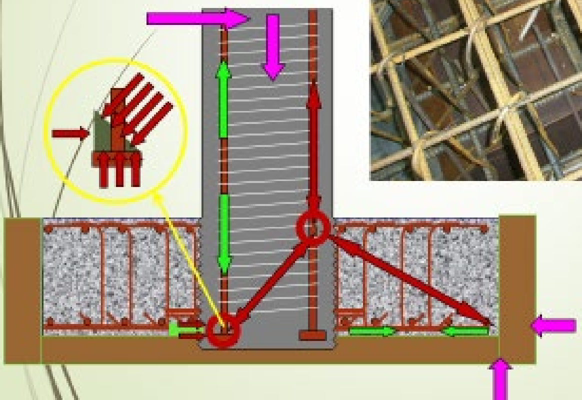


Column crushed at: 3.5 * (1.25DL + 1.75LL)

No damage to footing.

No sign of punching failure

Socket Connection – Internal Forces



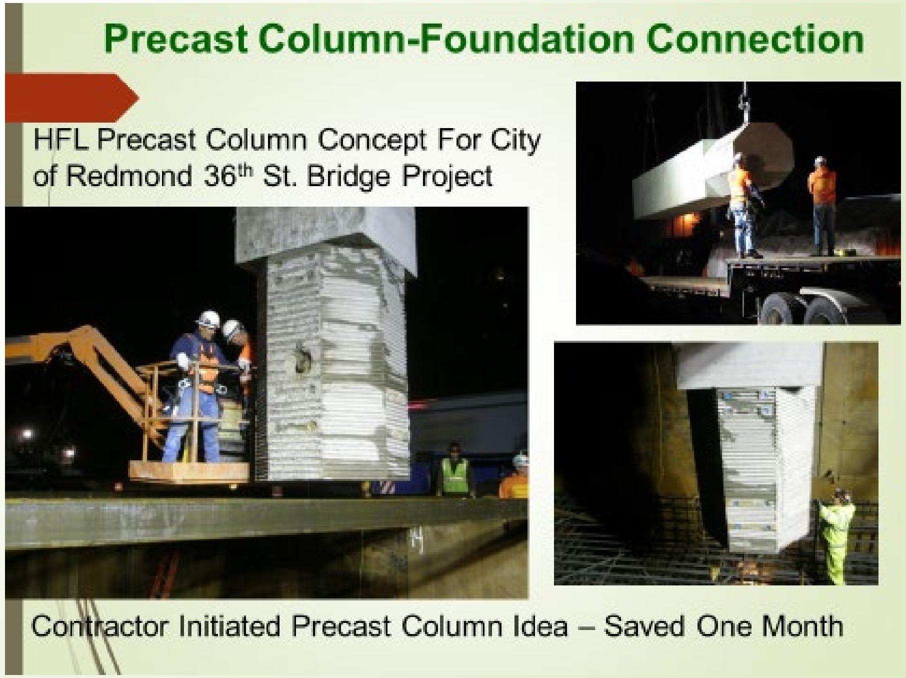
Precast Bridge System in High Seismic Regions - HFL

- PCI Journals
- Webinars
- Showcase

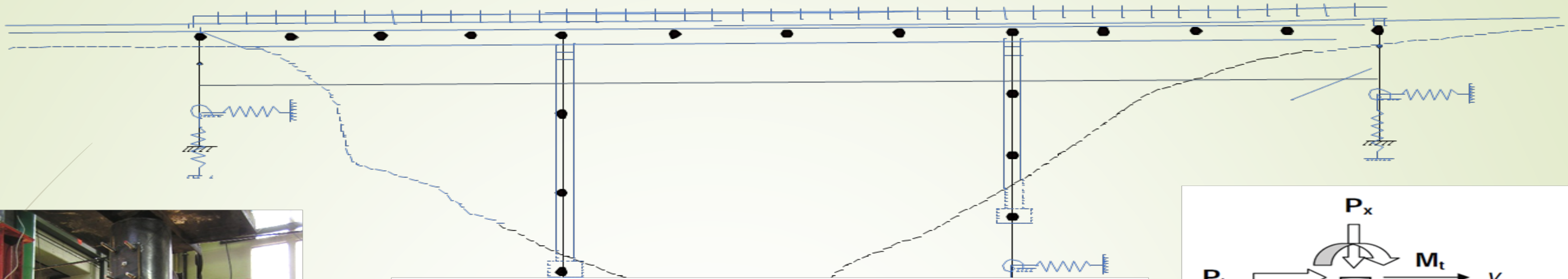
Precast Bent Cap Placement

- Two Erection Cranes
- Segment Weight :(120 &165 kips)
- 16 Duct Connection per Segment
- CIP Closure

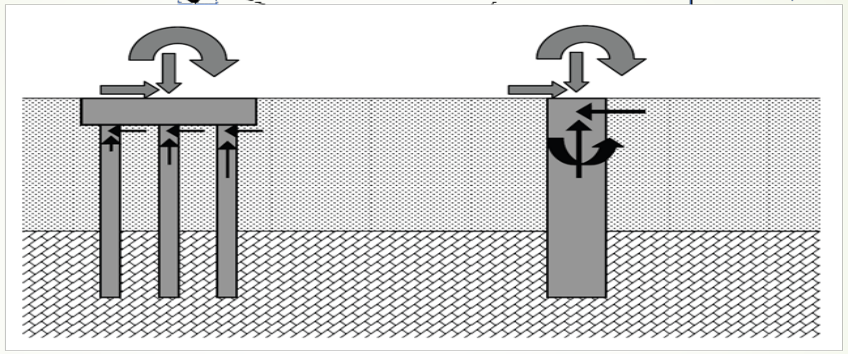
Examples of WSDOT ABC Projects



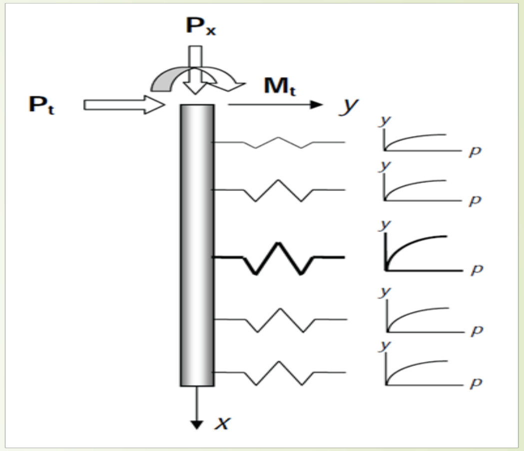
Concrete filled Steel Tubes



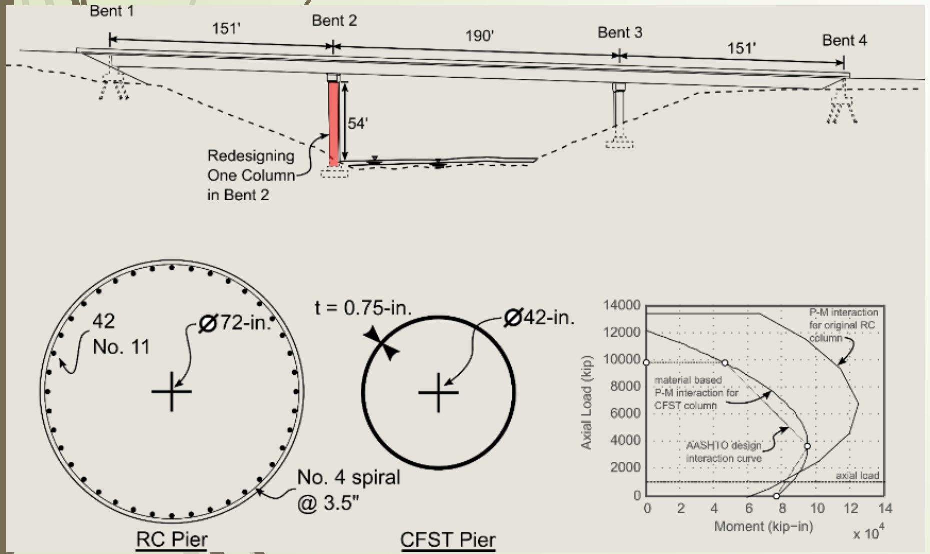
Ductility

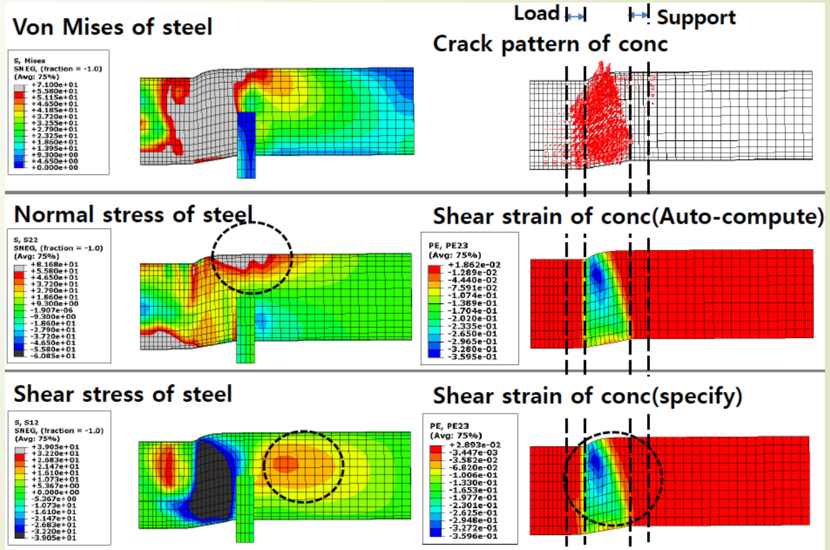


Deep Foundation



Lateral EQ Load





Two Level Performance Seismic Design Requirement

Two-level performance criteria are required for design of Essential and Critical bridges.

- FEE: 30% probability of exceedance in 75 years – 210 yrs Return Period
- SEE: 7% probability of exceedance in 75 years – 975 yrs Return Period

Bridges are considered as Critical, Essential, or Normal for their operational classification as described below.

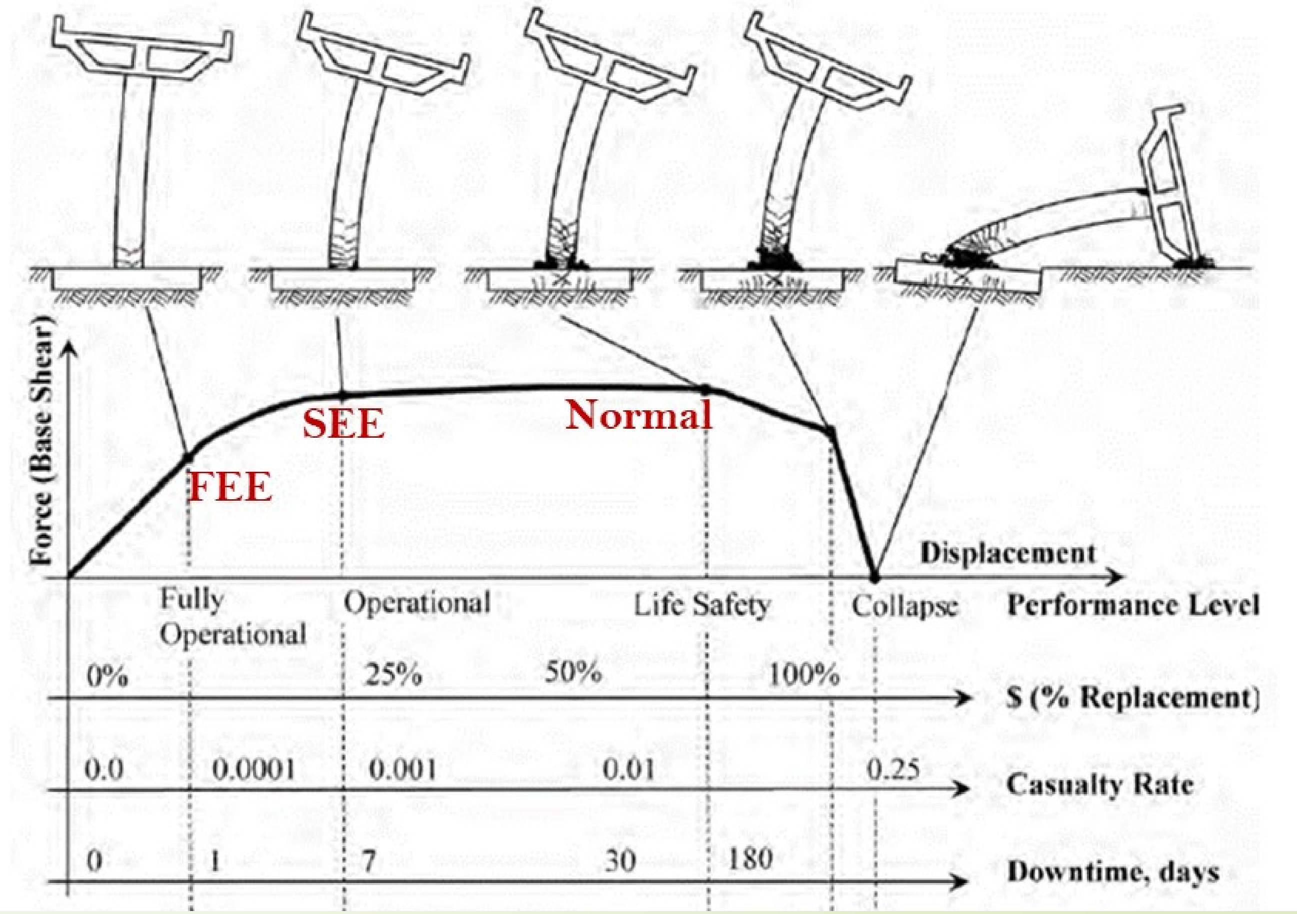
- **Critical Bridges -** are expected to provide immediate access to emergency and similar life-safety facilities after an earthquake.
- **Essential Bridges -** serve as vital links for rebuilding damaged areas and provide access to the public shortly after an earthquake. **All bridges within the seismic lifeline are considered Essential bridges.**
- **Normal Bridges -** All bridges away from Lifeline not designated as either Critical or Essential are designated as Normal.

Seismic Design Performance Criteria

- Normal Bridges: One Level
- Essential Bridges: Two Level
- Critical Bridges: Two Level

Bridge Operational Importance Category	Seismic Hazard Evaluation Level	Expected Post EQ Damage State	Expected Post EQ Service Level
Normal	SEE	Significant	No Service
Essential	SEE	Moderate	Limited Service
	FEE	Minimal	Full Service
Critical	SEE	Minimal to Moderate	Limited Service
	FEE	None to Minimal	Full Service

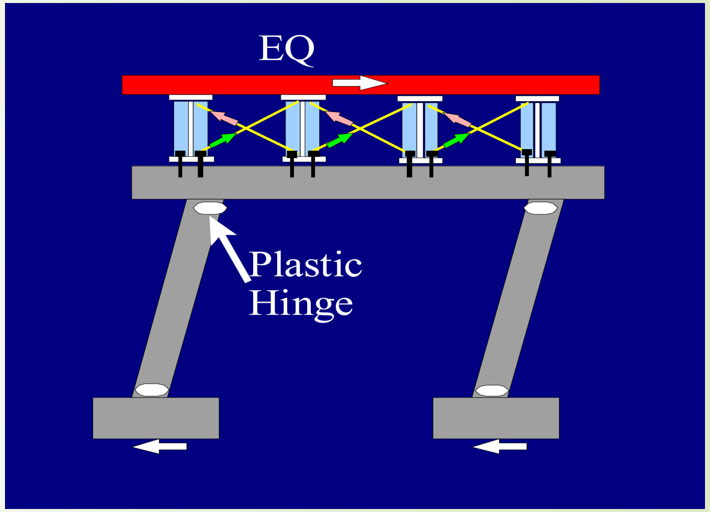
Seismic Critical Member	Displacement Ductility Demand Limits				
	Normal Bridges	Essential Bridges		Critical Bridges	
		SEE	FEE	SEE	FEE
Pier Wall in Weak Direction	5.0	2.5	1.5	1.5	1.0
Pier Wall in Strong Direction	1.0	1.0	1.0	1.0	1.0
Single Column Bent	5.0	2.5	1.5	1.5	1.0
Multiple Column Bent	6.0	3.5	2.0	1.5	1.0
Pile Column with Plastic Hinge at Top of Column	5.0	3.5	2.0	1.5	1.0
Pile Column with Plastic Hinge Below Ground	4.0	2.5	1.5	1.5	1.0
Superstructure	1.0	1.0	1.0	1.0	1.0



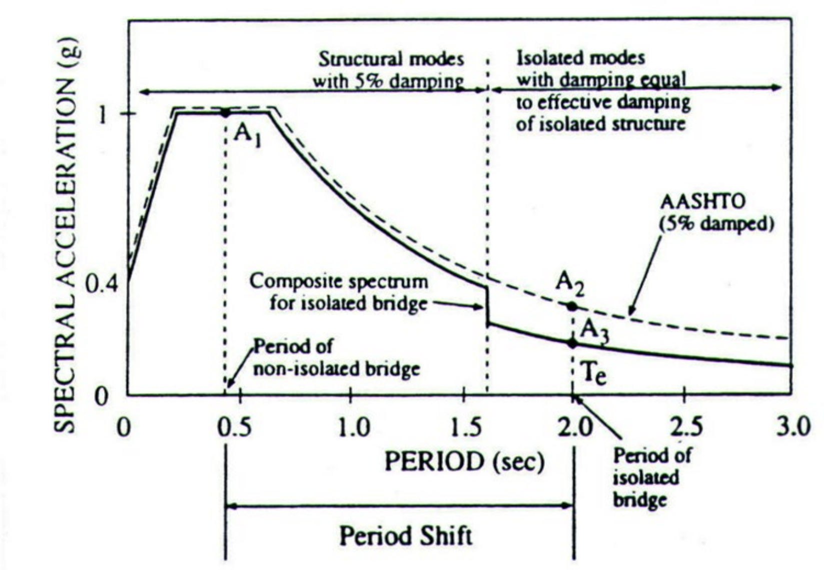
NCHRP: Performance Based Seismic Design

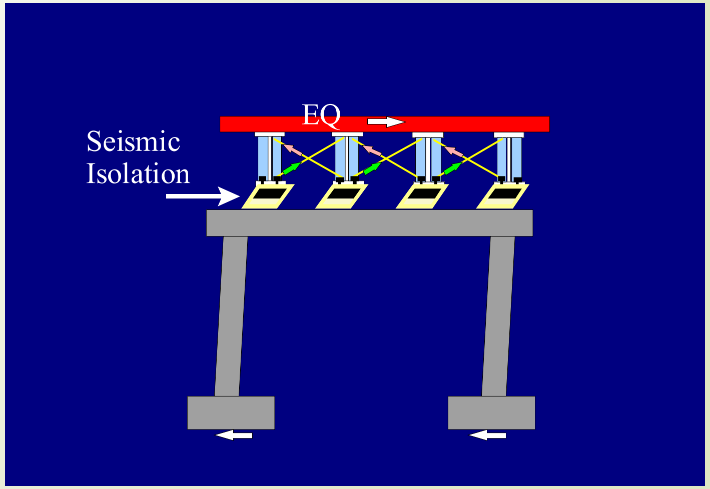
Use of isolation Bearings for Bridges

- Seismic isolation bearings are designed per LRFD, SGS, Isolation GS, and BDM.
- Expansion joints accommodate seismic movements required for isolation bearings to function properly.
- Adequate clearance at abutments for seismic displacement.
- Combinations of isolation bearings and conventional bridge column fixity are not allowed.

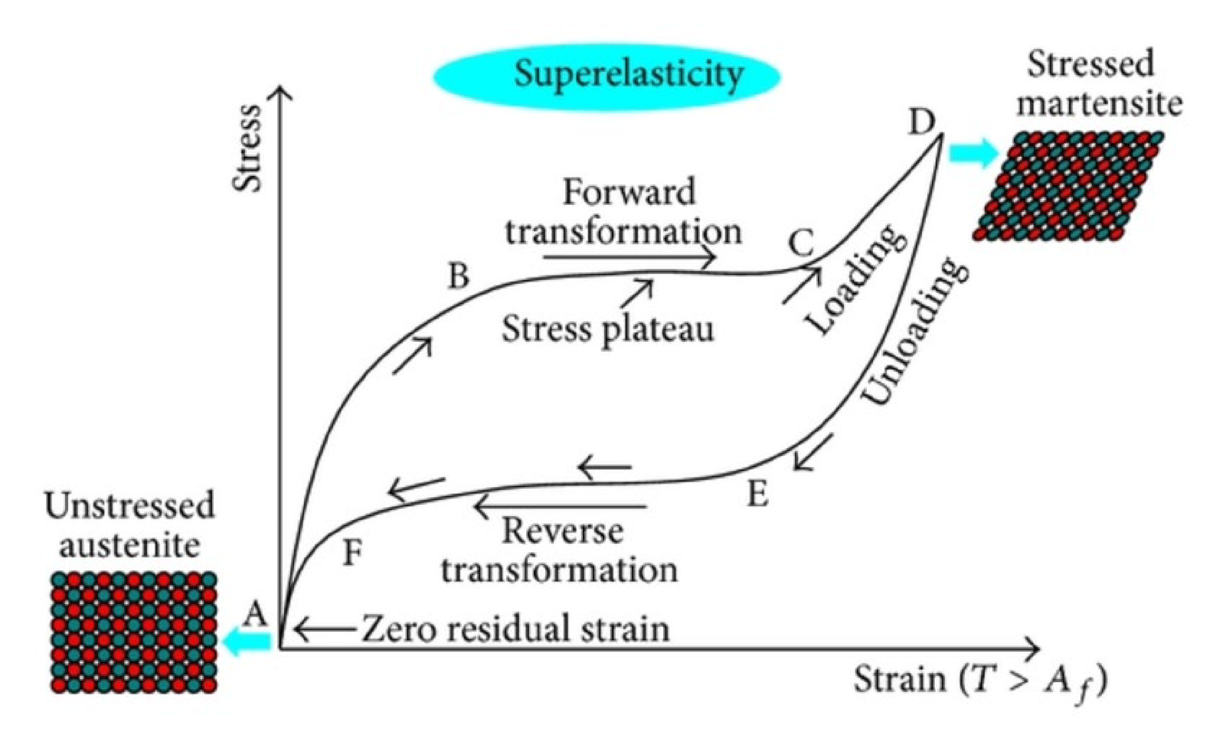


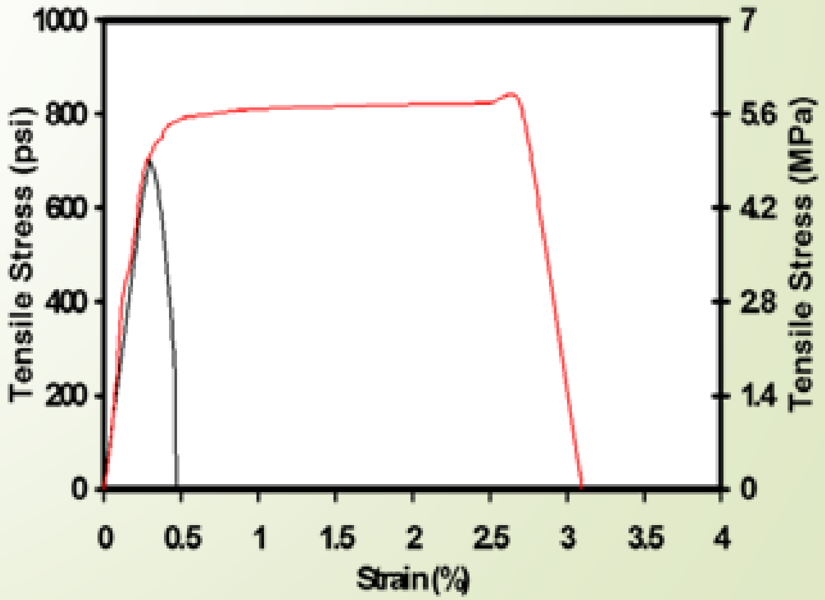
Parameter	Trans & Longit
Seismic Total Design Displacement range (TDD)	6 to 24 inches
Isolated Structure Effective Period (T)	2 to 3 seconds





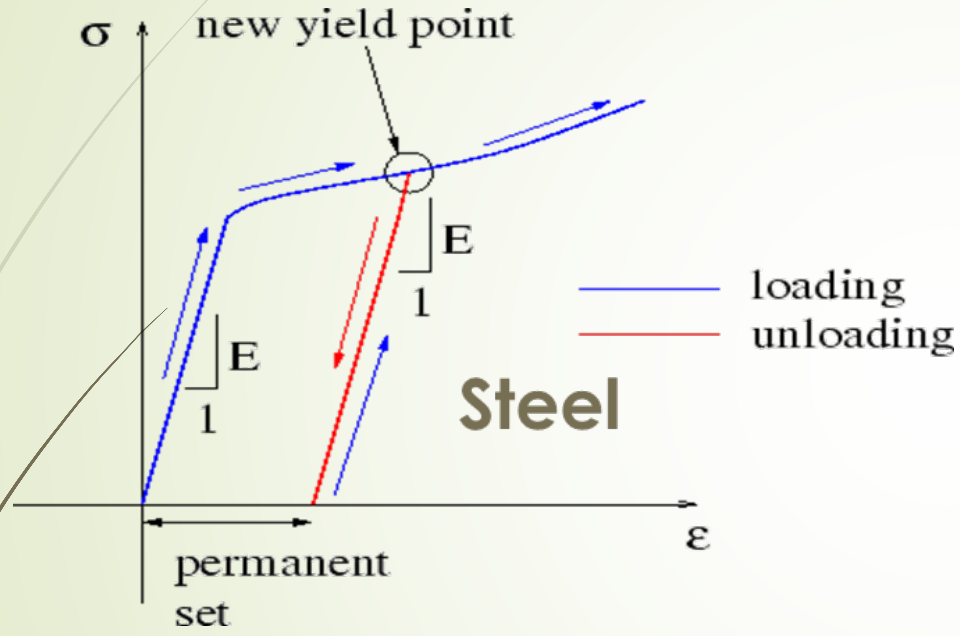
Innovative Bridge Design – Super Elastic Materials

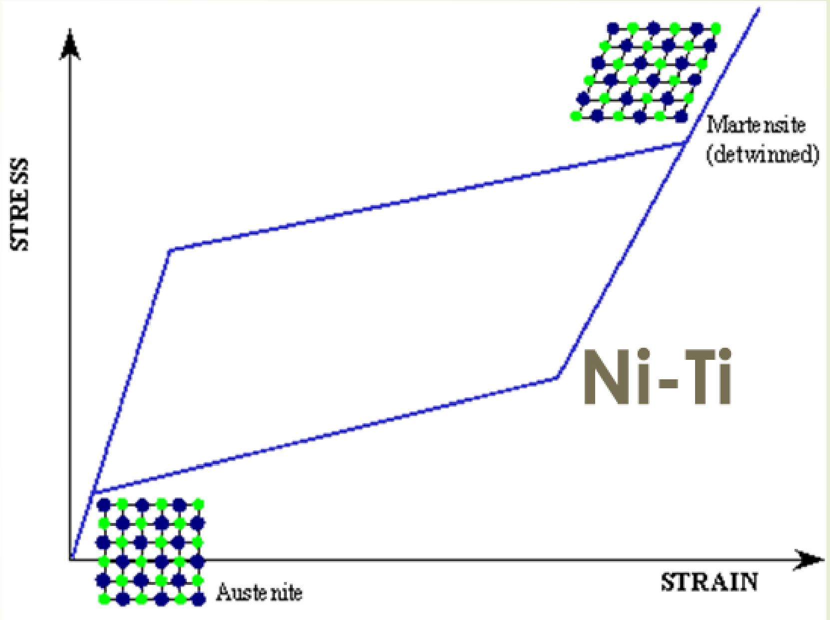




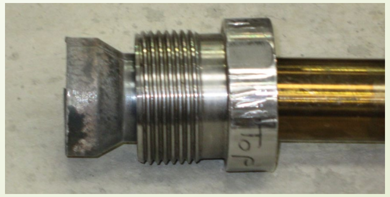
Innovative Super Elastic Materials - SMA

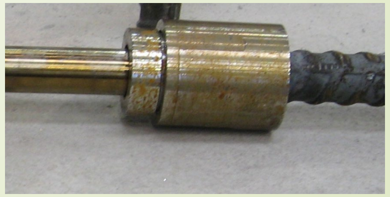
- Superelastic Nickel-Titanium Shape Memory Alloy (SMA) Bars
  - Reduce residual displacements





- **Challenges with including SMA**
  - Cost
  - Schedule – 6 month delivery, not including process to head bar for mechanical splice
  - Mechanical splice required in hinge region



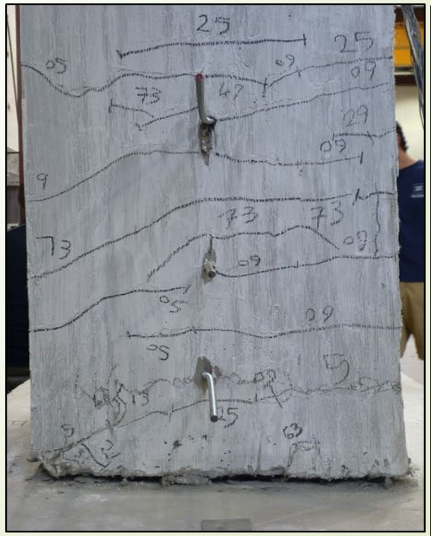


WSDOT Bridge Column Test - UNR

- Three - 0.4 Scale Columns
  - 2 Incorporating SMA and ECC
  - 1 Conventional RC
- 62 in clear height
- 18 in x 18 in cross-section
- Cyclic loading

Damage at End of Testing

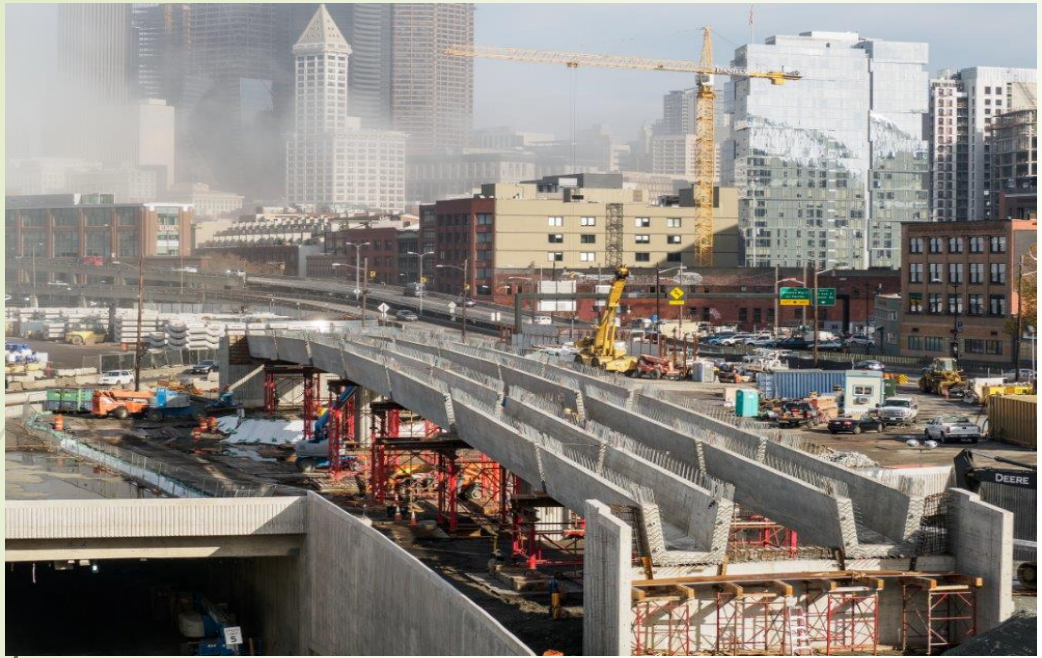
SR99-RC (8% Drift)

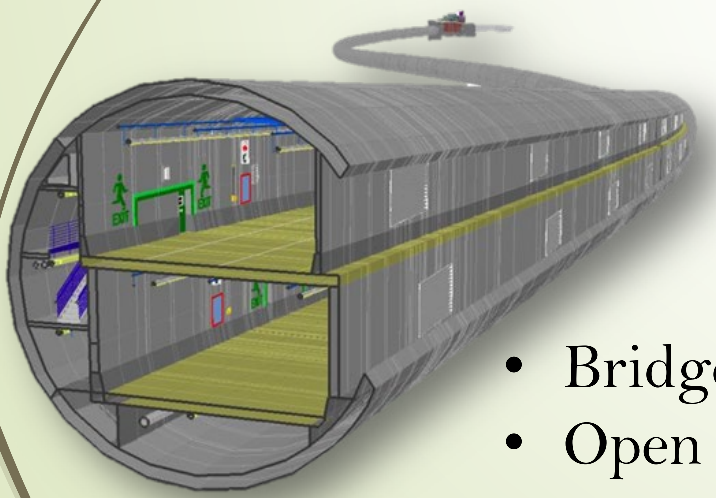


SR99-LSE (12% Drift)

SR99-SSE (10% Drift)

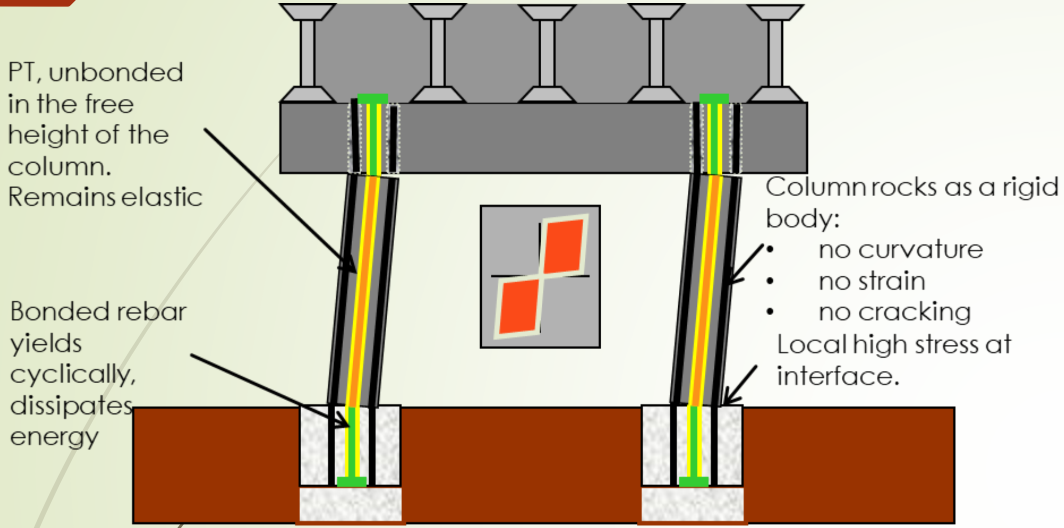
SR 99 South Tunnel off Ramp Access

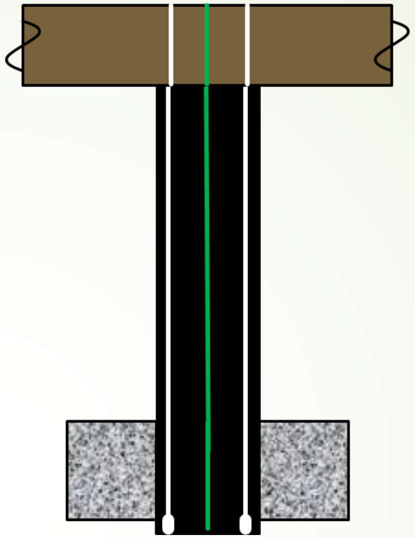


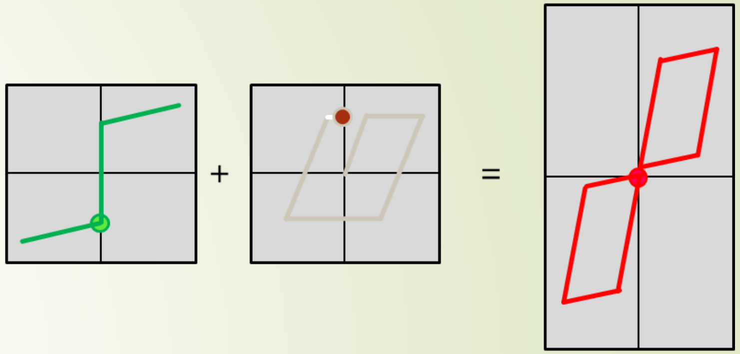


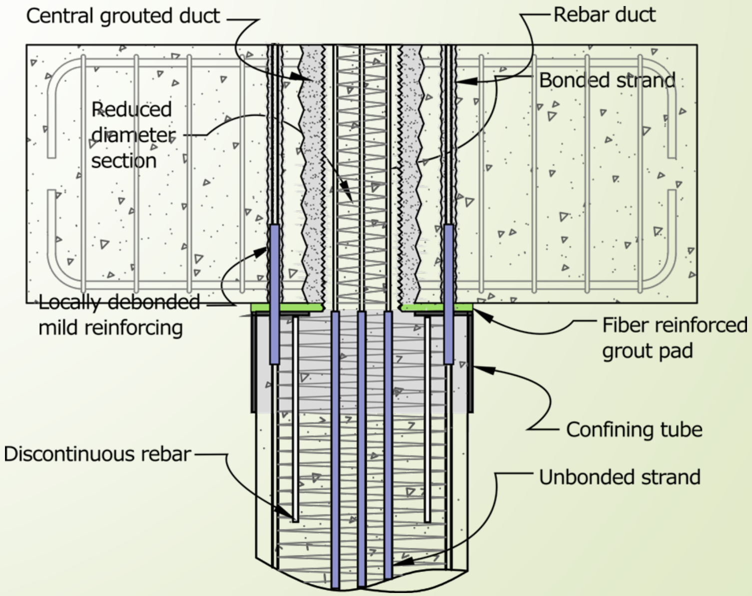
- Bridge Completed in 2018
- Open to traffic 2/2019

Seismic Resiliency – Self Centering Precast Columns

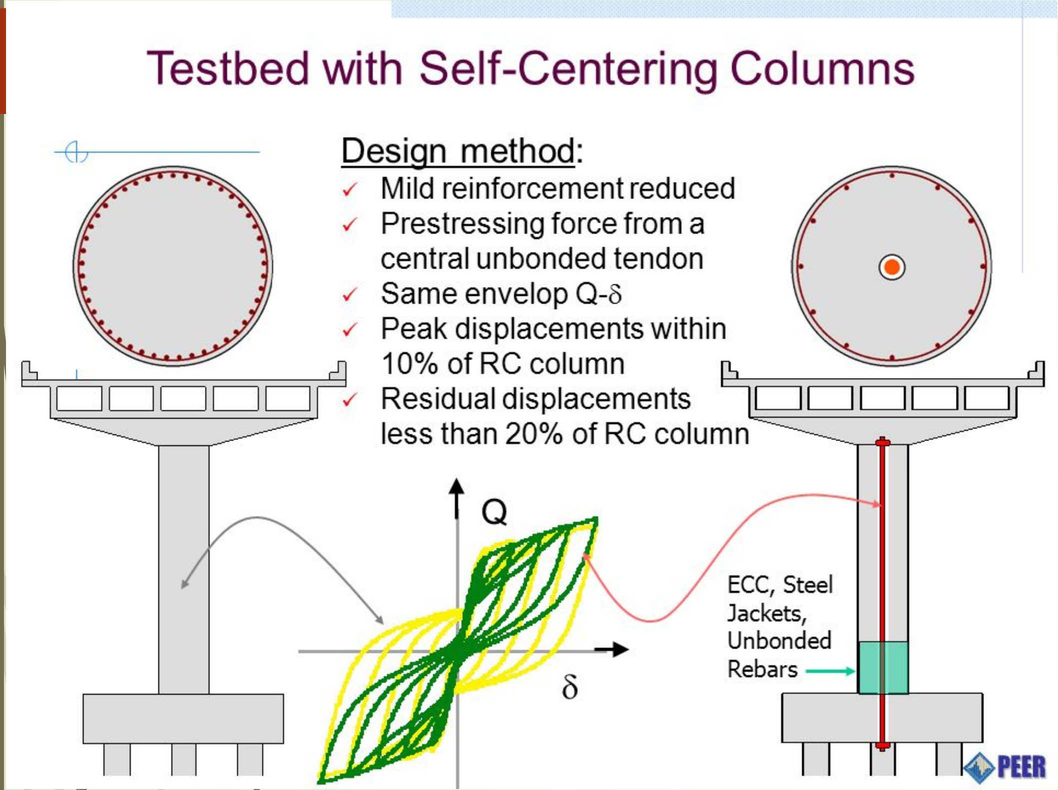


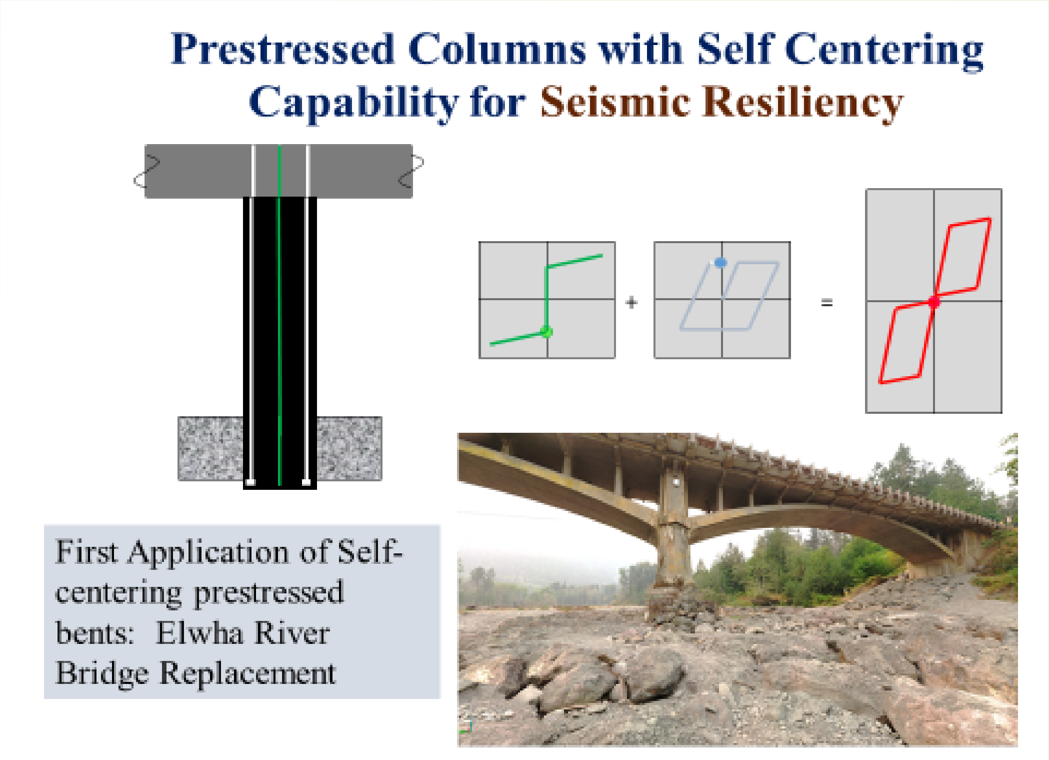


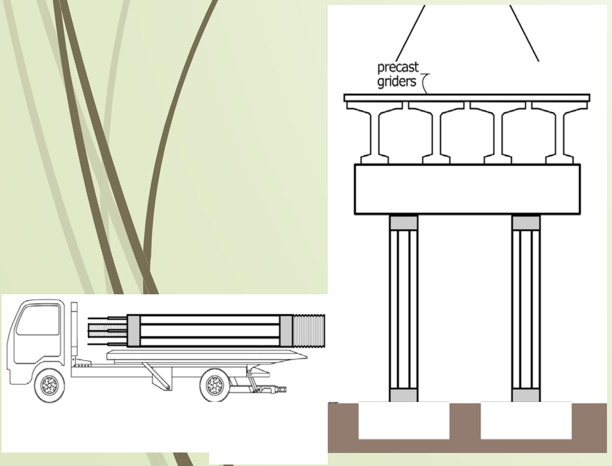


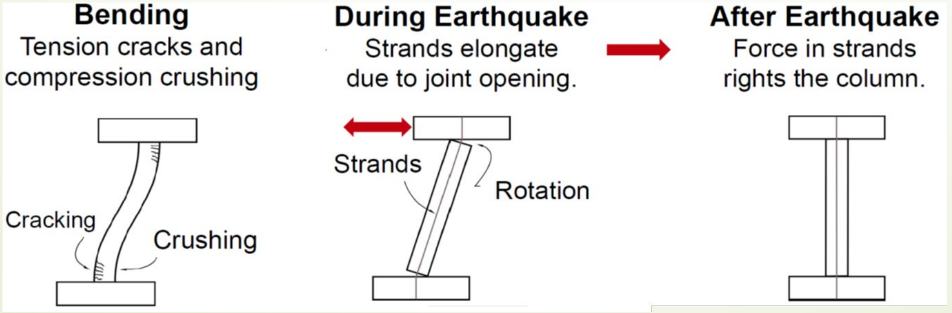


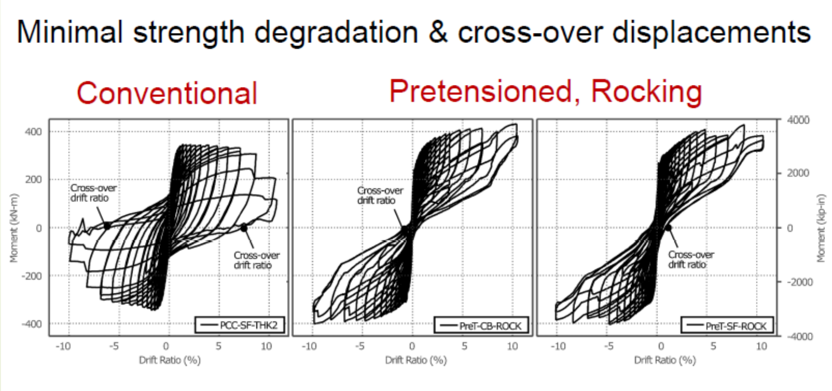
Seismic Resiliency – Self Centering Precast Columns



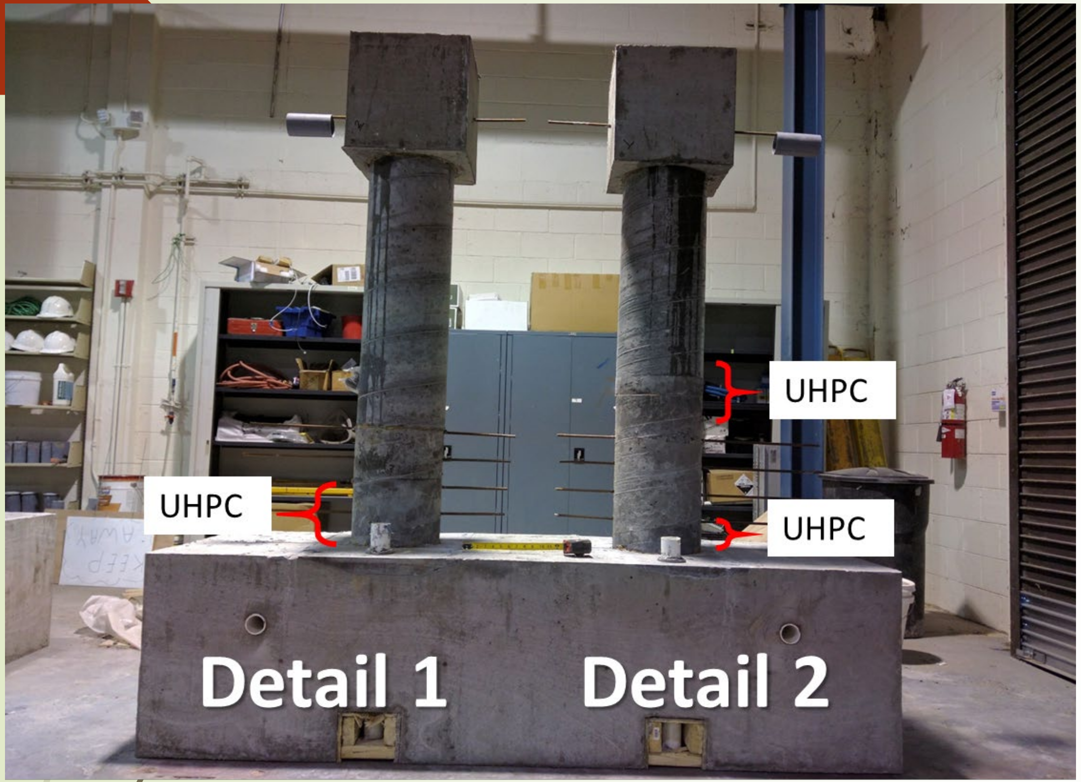


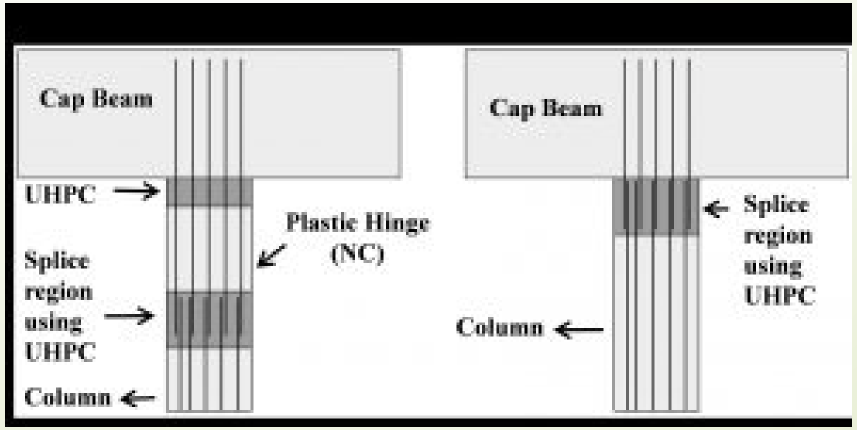






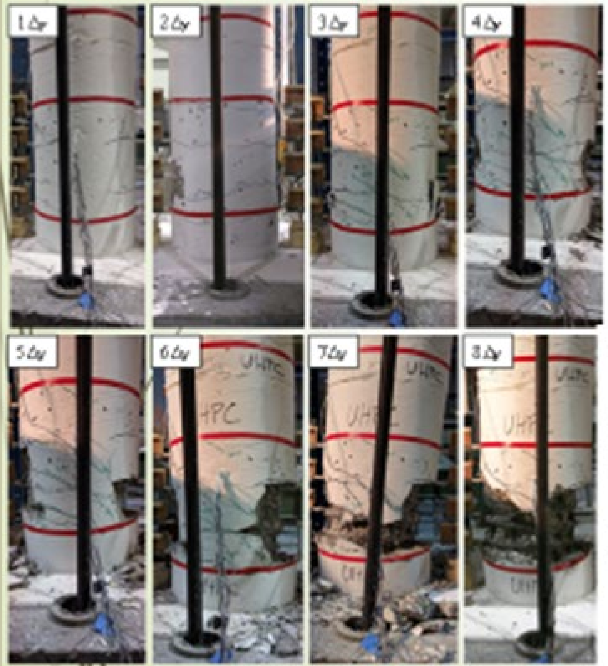
Seismic Resiliency – UHPC for Column PH Regions

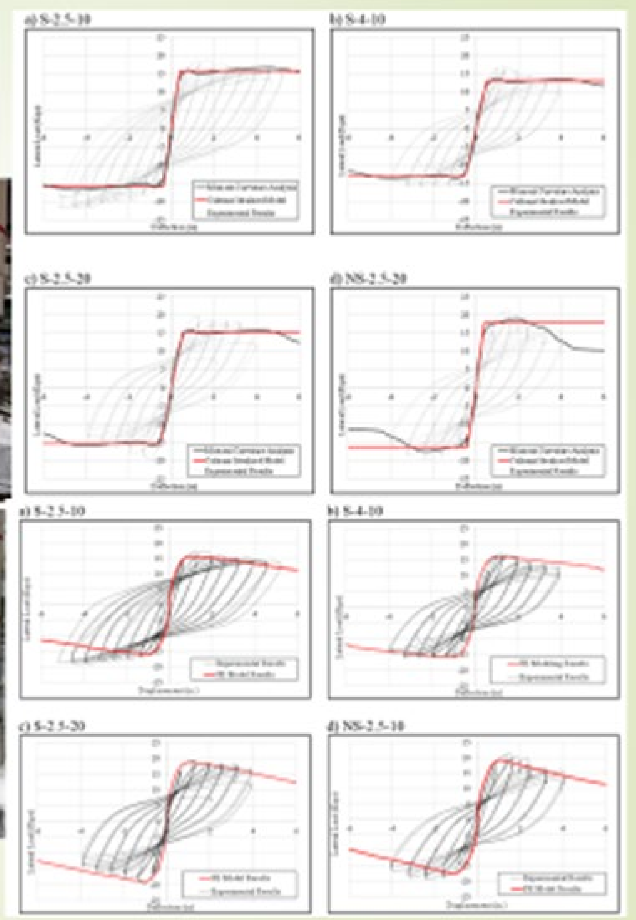




Proposed Research: FIU-UHPC Connection Tests

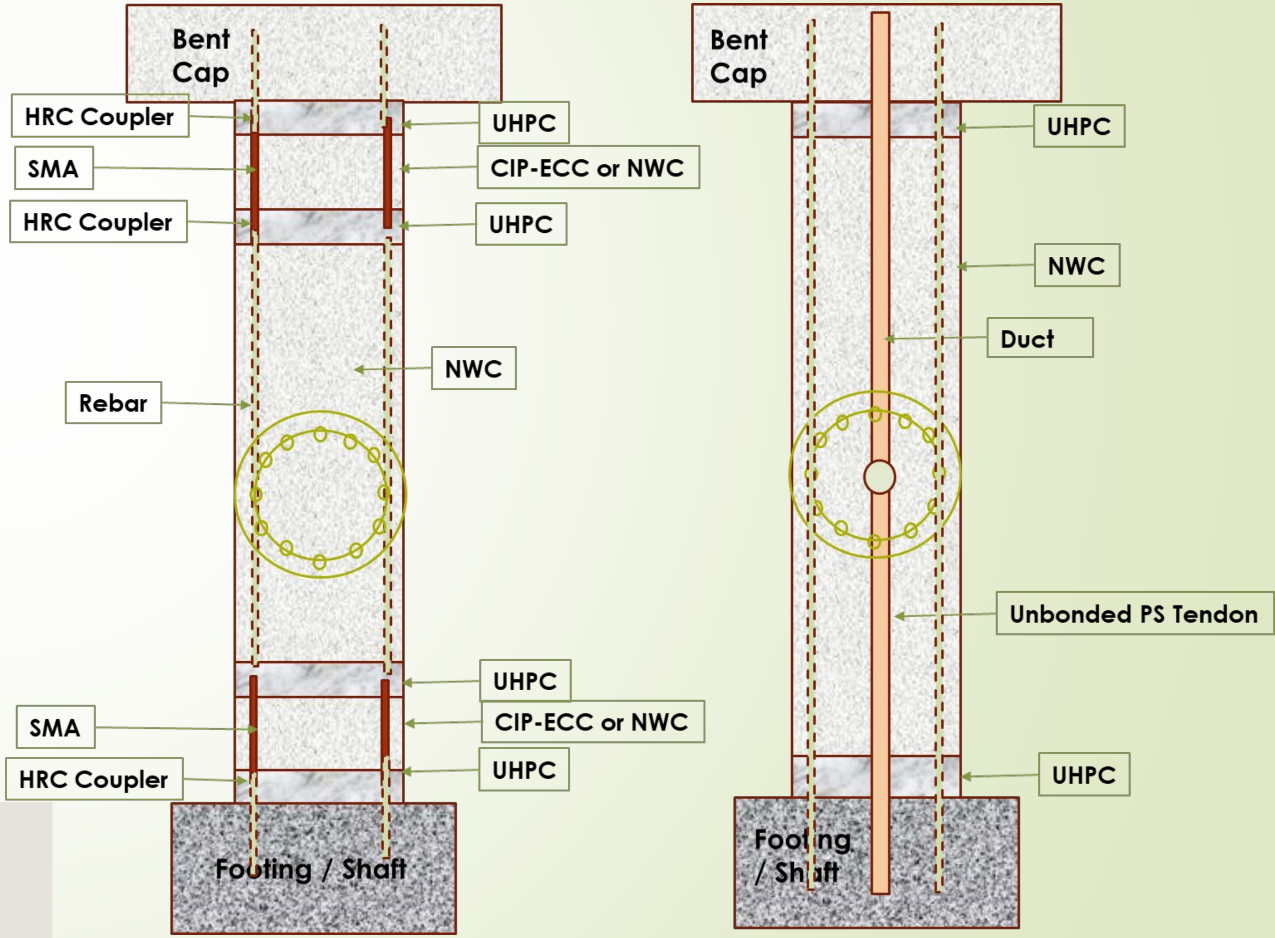
Specimen
Seismic Detail





UHPC + Shape Memory Alloy in Plastic Hinging zone and ECC

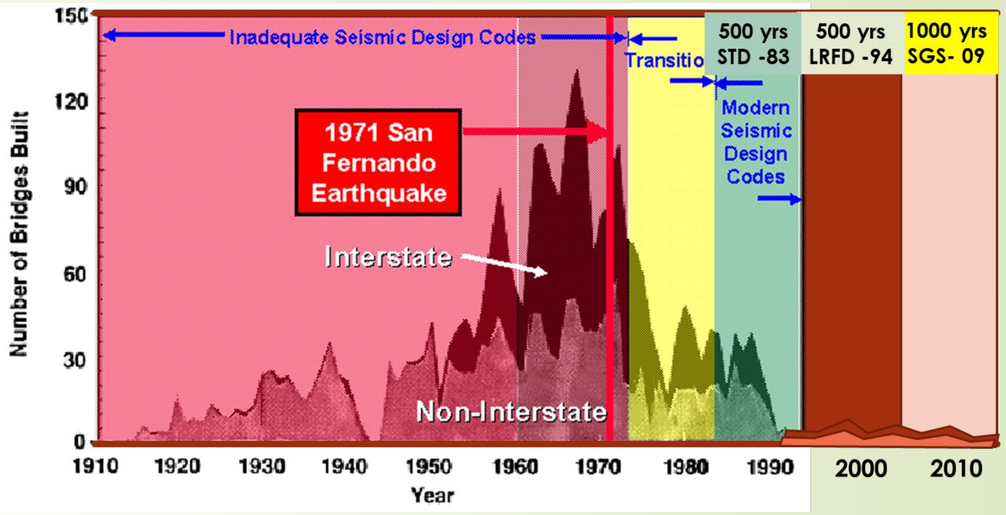
Proposed FIU tests with Self Centering



2019-21 Biennium Bridge Research Projects:

- Performance of Steel Jacket Retrofitted Reinforced Concrete Bridge Columns in Cascadia Subduction Zone Earthquakes

- Effects of Cascadia Subduction Zone M9 Earthquakes on Bridges in Washington State



Bijan Khaleghi, Bijan.Khaleghi@wsdot.wa.gov