Performance-Based Concepts on Pacific Northwest Infrastructure Projects

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Presentation Outline

- Performance-Based Seismic Design
- Example Case Studies
  - Marine structure with buildings
  - Bridge
  - Reservoirs

Ancient Performance-Based Design

1947 Kon Tiki Voyage

Thor Heyerdahl
Ancient Peruvian Raft Technology
101 days, 5000 miles
From Peru westward to Polynesia

- Balsa logs lashed together
- "No nails or rivets, no rigid joints"
- "Had to be as elastic and pliable as possible"

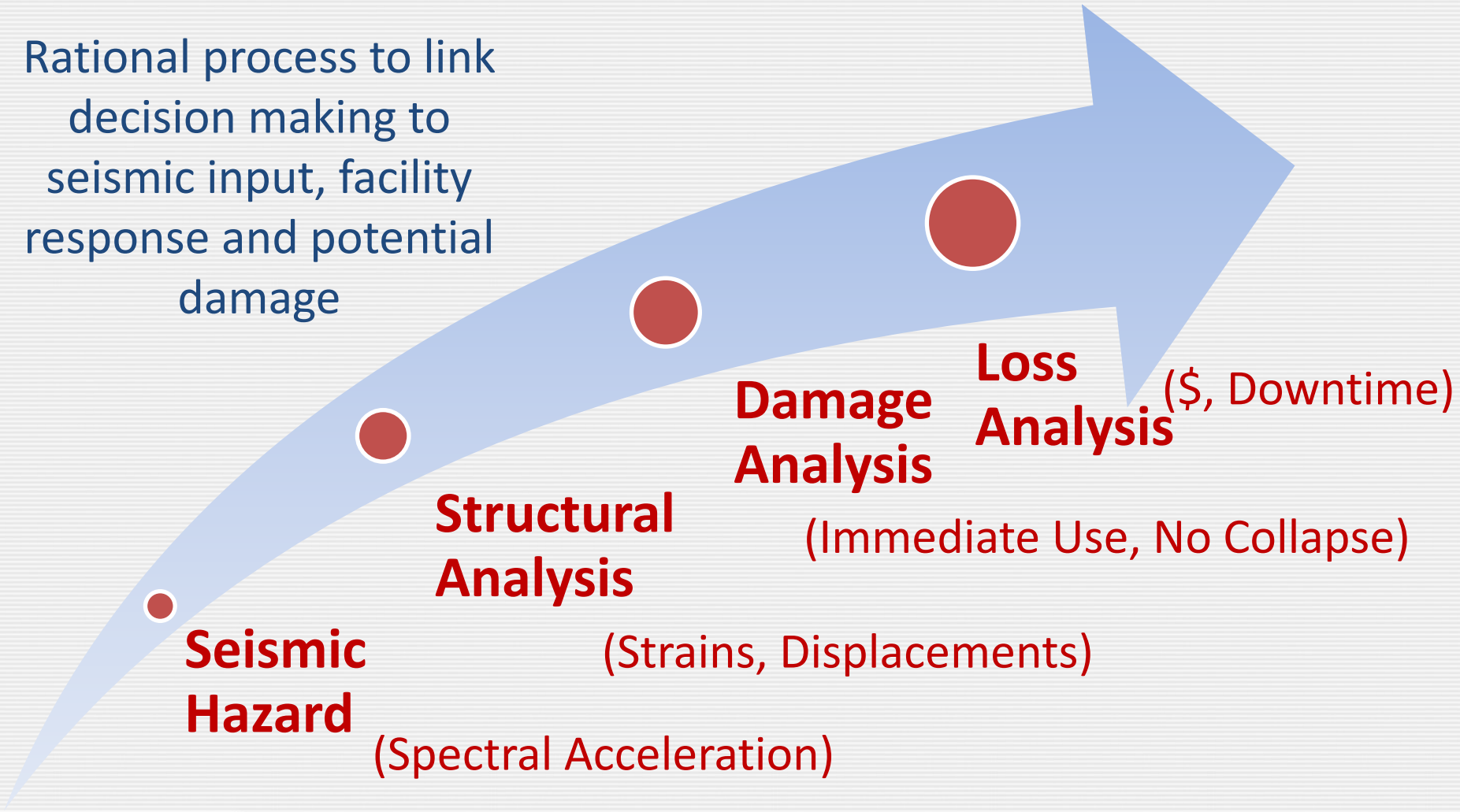
"Among primitive races, the golden rule was don't resist nature; yield to her command and accommodate"

… a precursor of modern displacement-based and capacity design principles

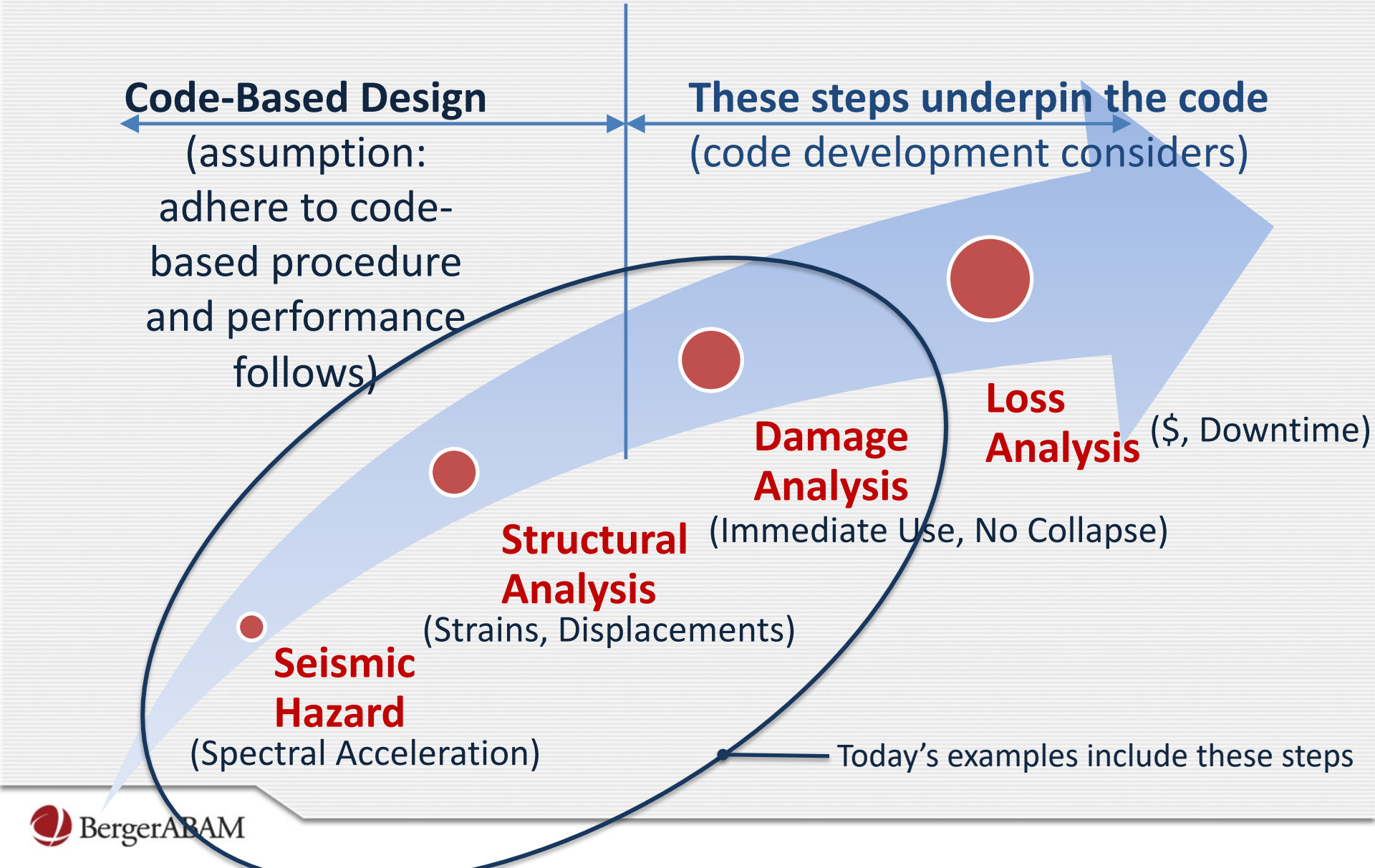
From 1950 documentary film "Kon Tiki"
Thor Heyerdahl & The Kon Tiki Museum
Oslo, Norway, Copyright 1995

Performance-Based Seismic Design - PBSD

Rational process to link decision making to seismic input, facility response and potential damage



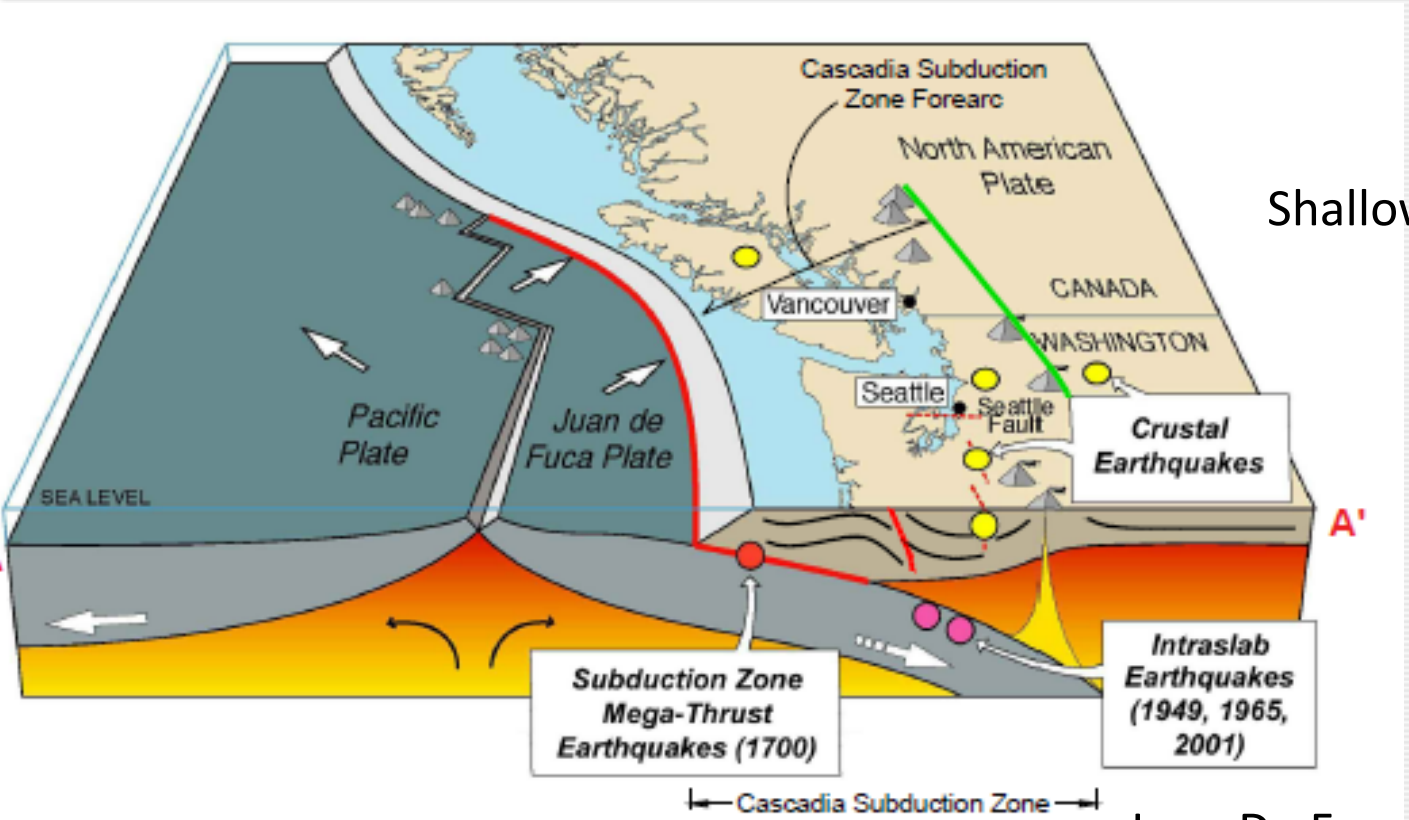
PBSD vs Conventional Code-Based Approach



True Performance-Based Design

- Choices
- Meet minimum Life Safety, enhance beyond
- Optional (beyond the code)
- Requires Owner, Engineer, AHJ to agree and document approach
- Sets a new Standard of Care

Puget Sound Seismic Sources



Shallow Crustal Faults

Juan De Fuca Intraslab Zone

Cascadia Subduction Zone Mega-Thrust (Interplate)

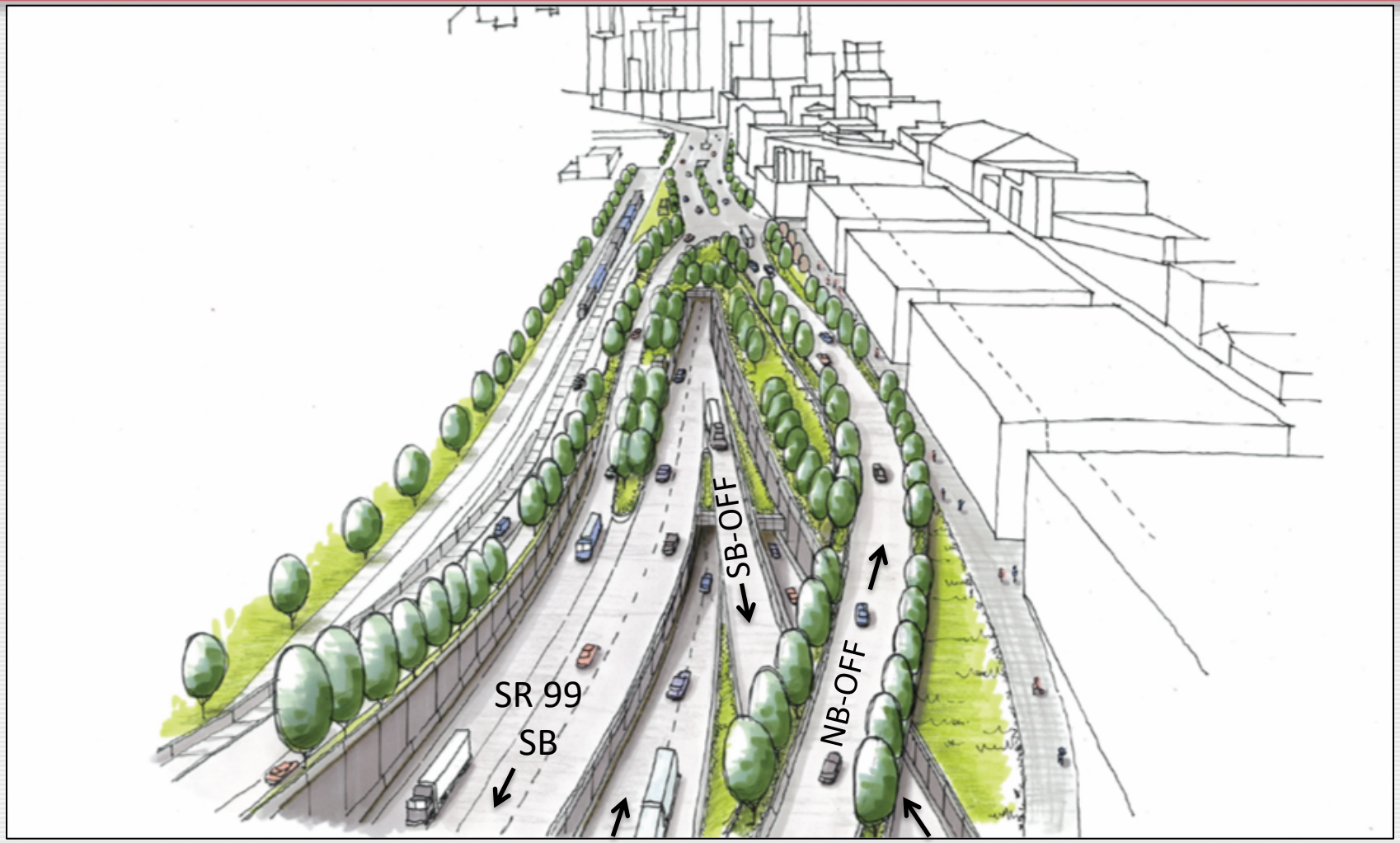
USGS

Example 1: Buildings on Pier – Not Available for Posting

Example 2: Highway Bridge with Advanced Materials

- Three-span flyover ramp
- Demonstration project – WSDOT
- Testing - UNR
- Use Shape Memory Alloy (SMA) and Engineered Cementitious Composite (ECC) for column plastic hinge zone
- Minimal damage expected in columns

SR 99 South Access – NB Off Ramp

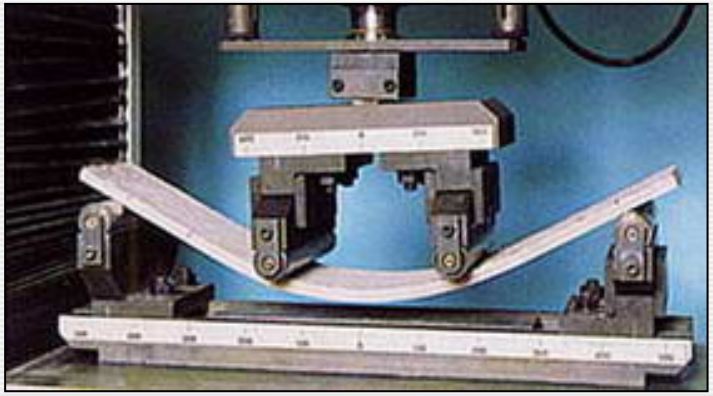


Rendering of NB Off Ramp

Owner: Washington State Department of Transportation
Engineer: Washington State Department of Transportation

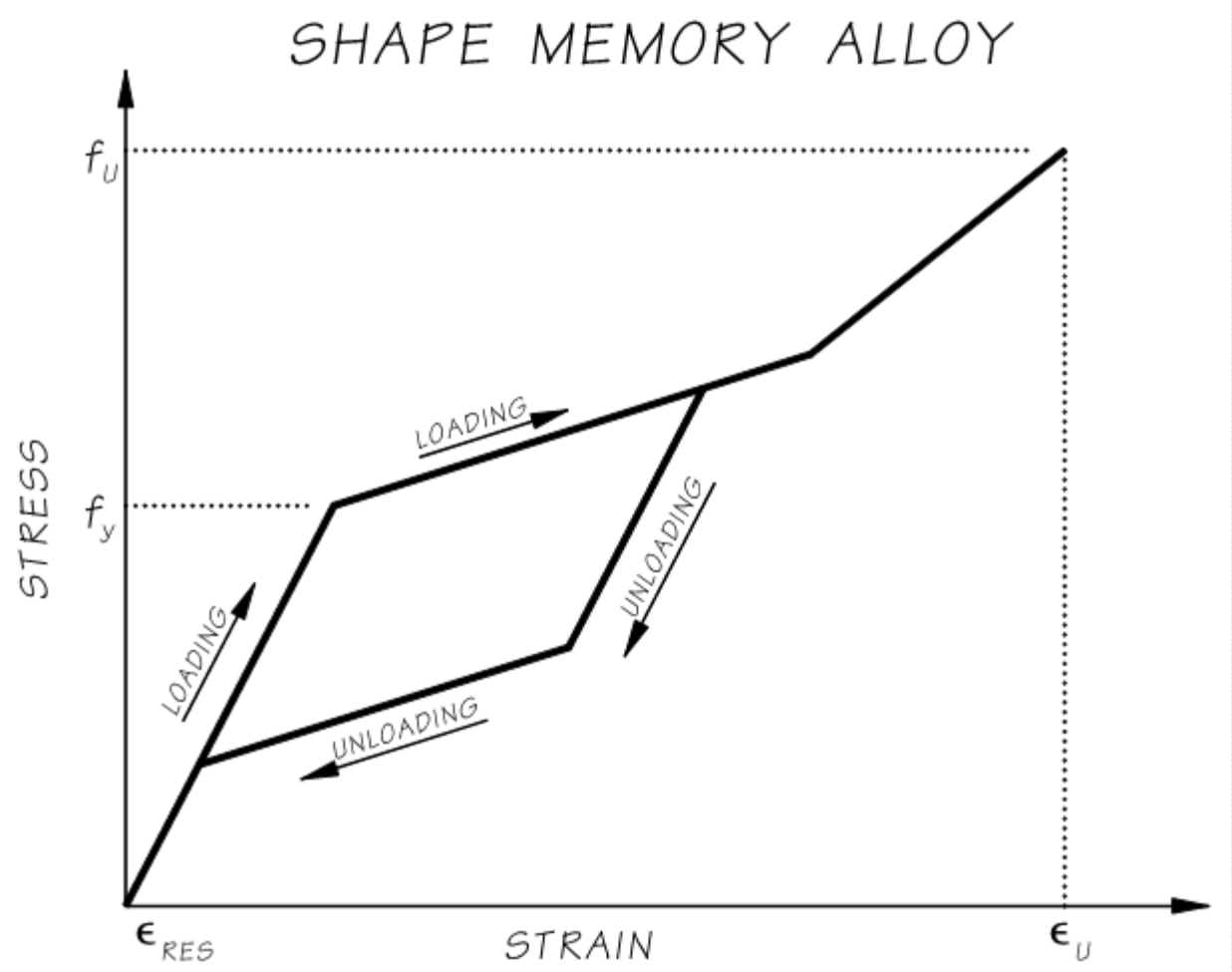
Innovative Materials

- Shape Memory Alloy Bars (SMA)



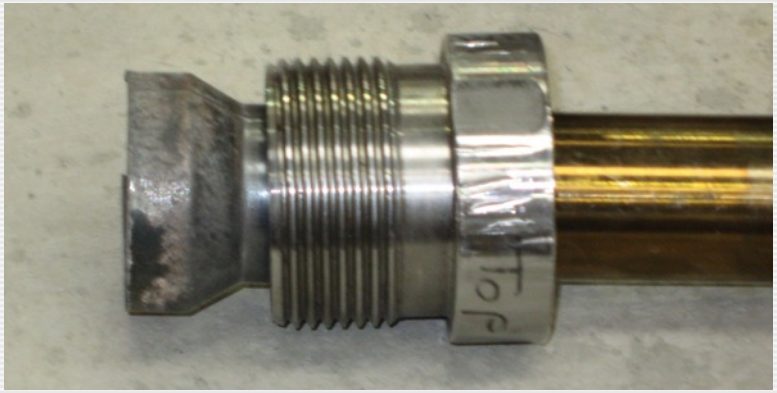
- Engineered Cementitious Composite (ECC)

Innovative Materials SMA



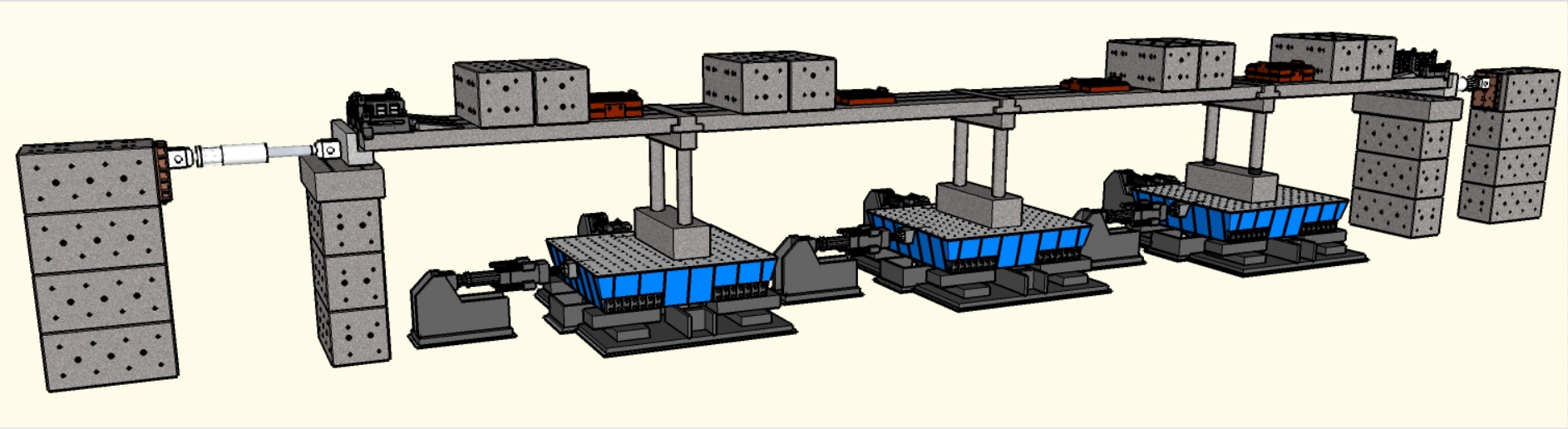
SR 99 South Access – NB Off Ramp

- Challenges with including SMA
  - Cost
    - ASTM A706 = $1 / lb. (installed)
    - SMA = $92 / lb. (delivered)
  - Schedule – 6 month delivery, not including process to head bar for mechanical splice
  - Mechanical splice required in hinge region



Spliced SMA Bars into Column Cage

Innovative Materials Bridge Research



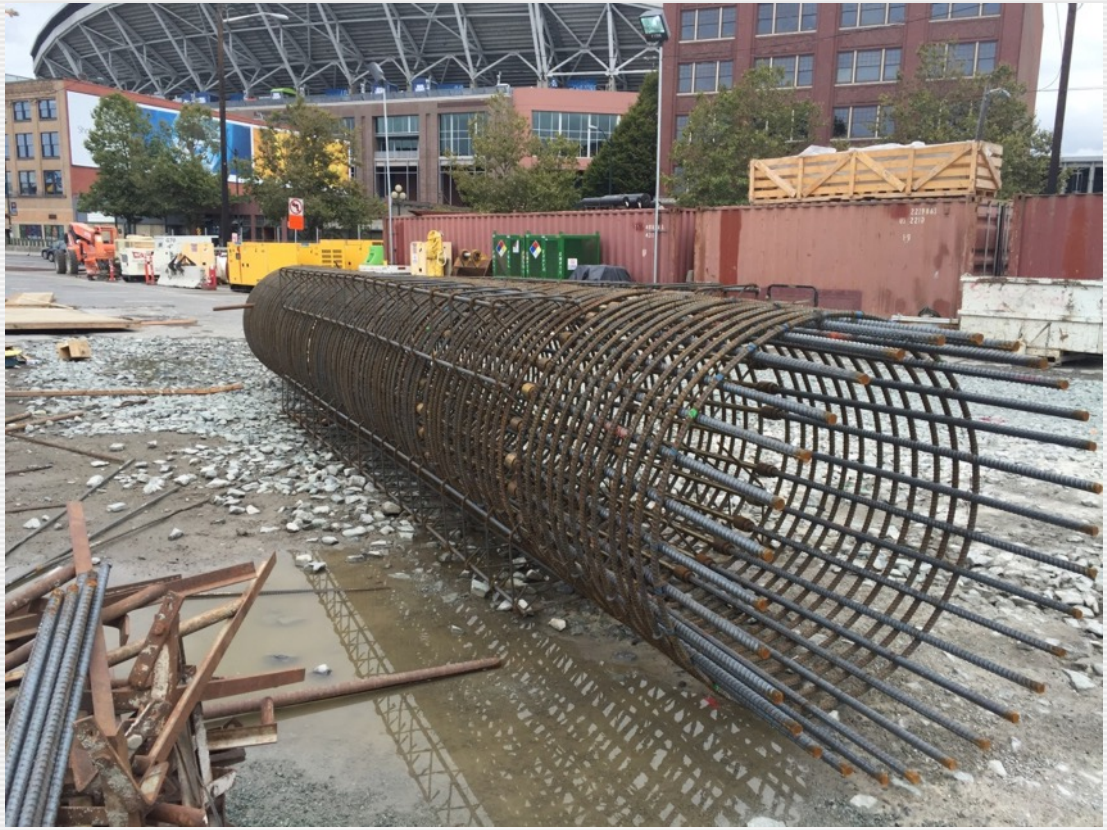
- ¼ Scale, 4 Span Bridge, Total Length=110ft
- Innovative Materials in Bottom Plastic Hinges
- Conventional RC in Top Plastic Hinges

University of Nevada, Reno

NSF

NEES

SR 99 South Access – NB Off Ramp Construction Photos



Service and Seismic Performance

- Non-seismic limit states require attention due to flexibility of SMA
- Seismic: Upper column plastic-hinge zones – minimal to no damage
- In-ground plastic-hinge zone – does not reach inelastic response in design 1000-yr event
- Abutment shear keys will likely experience damage in design event

Example 3: SPU Buried Reservoir Seismic Program

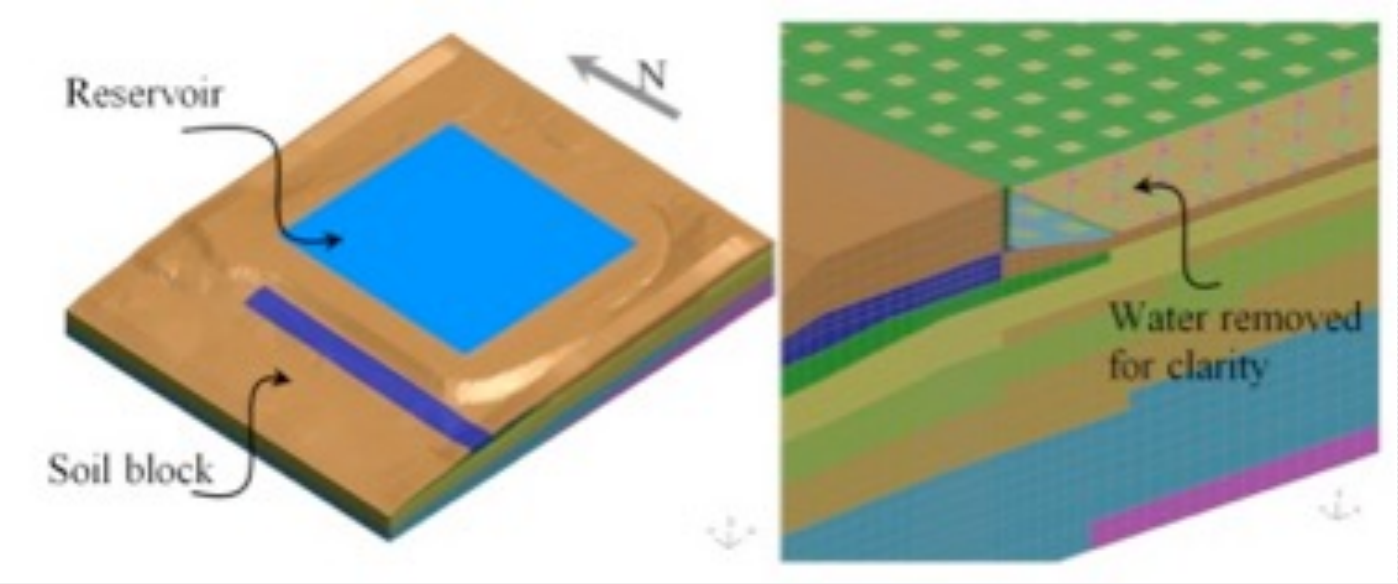
- Four reservoirs
- Potable water and fire suppression storage
- Enhanced performance
  - 100-yr operational
  - MCE no collapse, limited leakage
- Site-specific, 3D, SSI response history assessment

Owner: Seattle Public Utilities
Team: CH2M, SC Solutions, Shannon & Wilson
PRP: Y. Hashash, S. Kramer, L. Marsh

SPU – Beacon Hill Reservoir

- 50 MG capacity
- Largest single cell reservoir of the four at 540’ by 500’ by 25’+/-
- Proportion of reservoir – “pizza box”
- Significant slope to west w/ weak soil layer
- Cut into hillside at SE
- Public park on top

Site, Structure, and Water Modeled



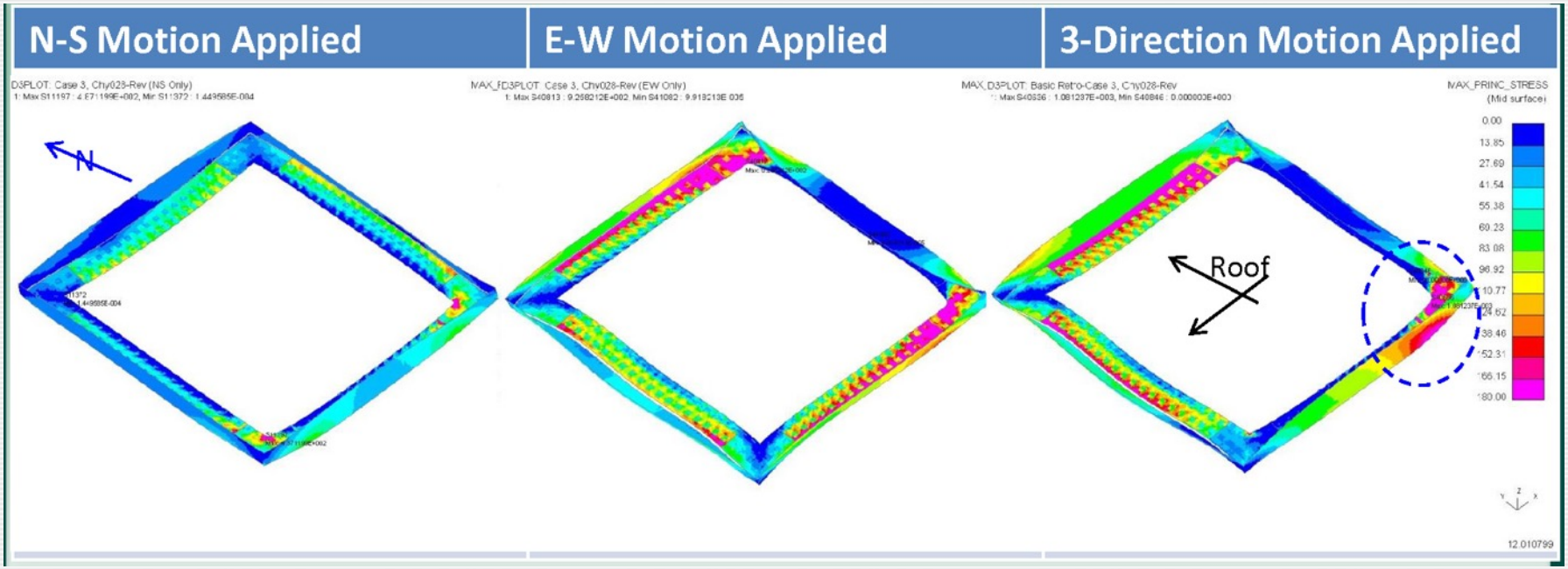
- Primary modeling with LS DYNA
- Spectrum compatible CMS acceleration history input
- Gapping, sliding, and soil nonlinearity included
- Separate slope-stability detailed assessment

Interior View of Reservoir

West Seattle Reservoir

Drag Forces through the Structure

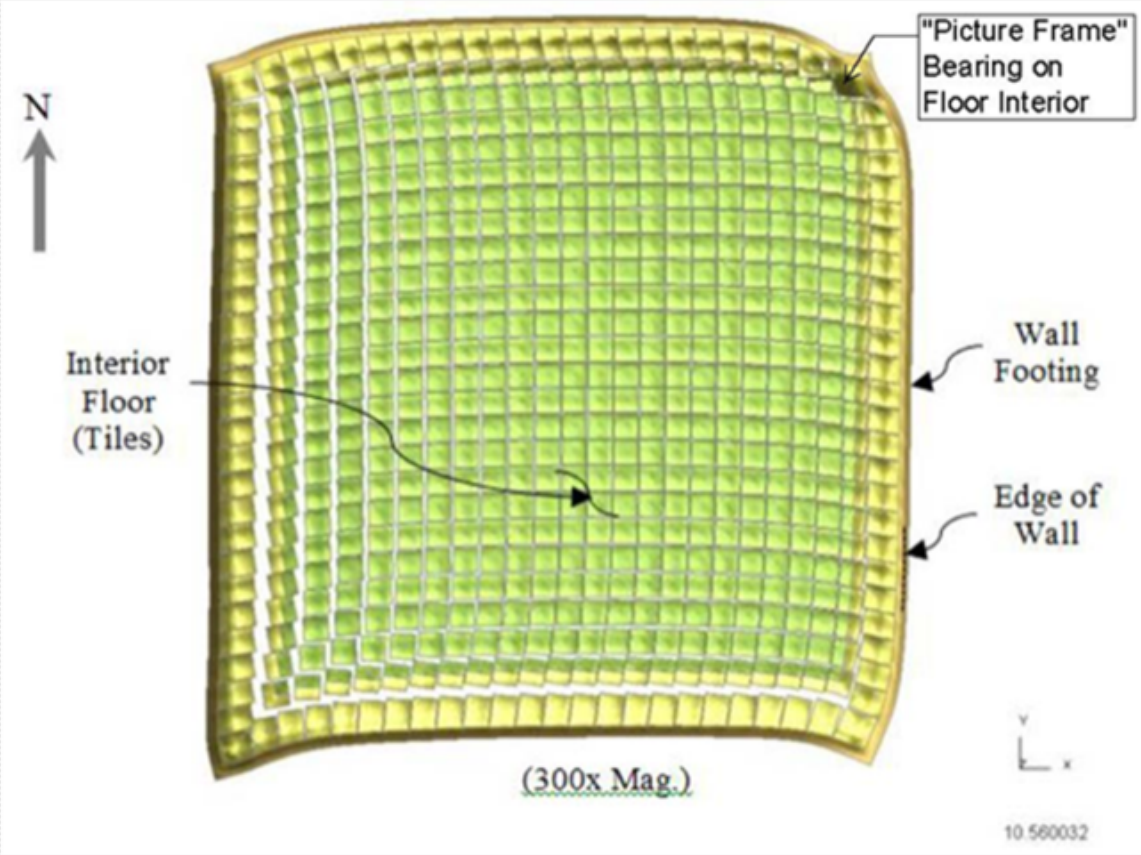
Drag forces arise around perimeter “picture frame” at base of walls



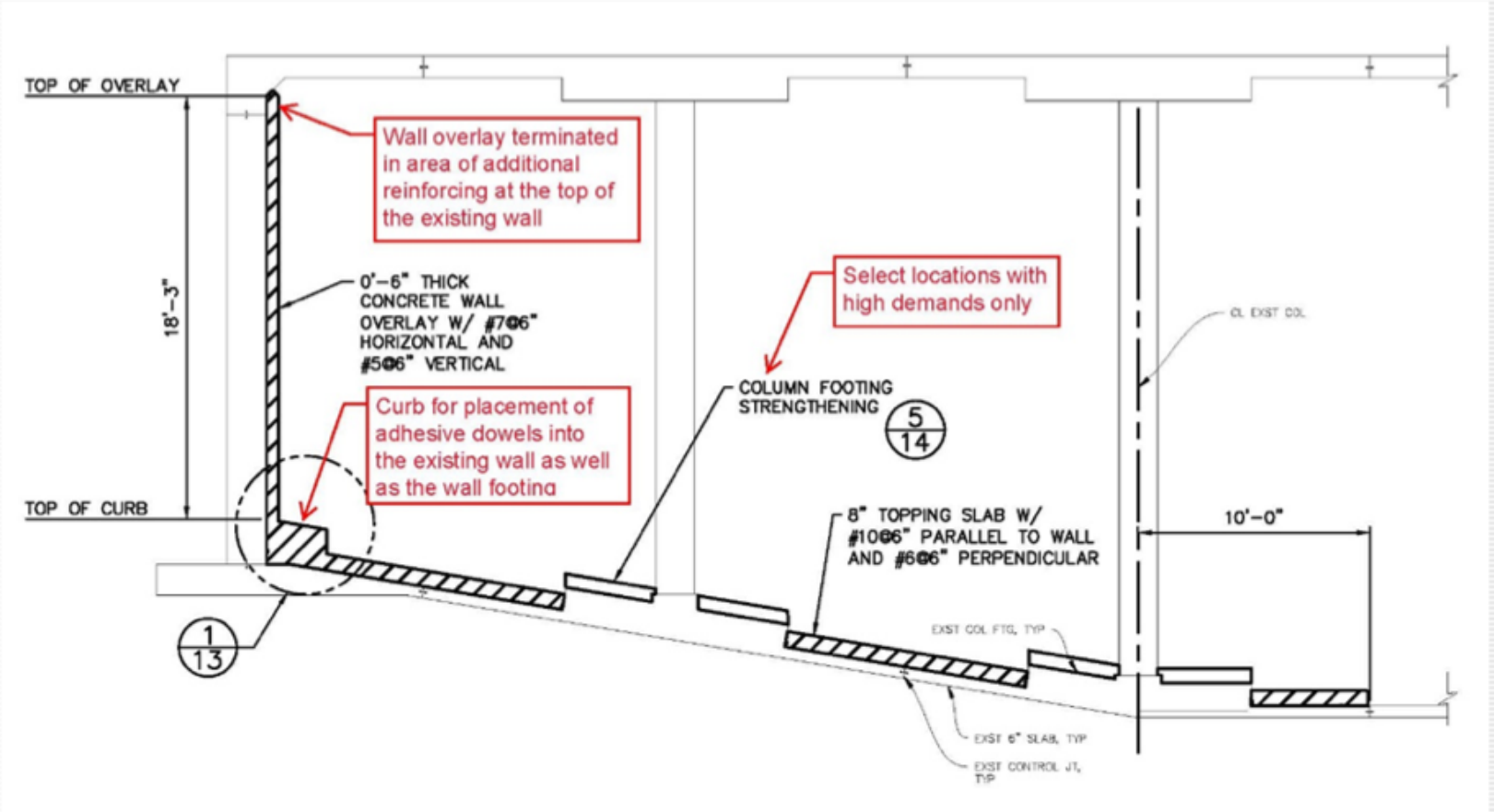
Sources of Axial Tension

Drag forces originate in the floor “picture frame” as the inertial shears propagate down the walls, which slide due to limited weight.

Large tensions also induced in walls and roof due to flexure.



Structural Retrofit Components



Beacon Reservoir

Photo of Floor Overlay Retrofit

West Seattle Reservoir

Summary

- Performance-based seismic concepts are being applied to non-building infrastructure in the Pacific Northwest
- Must have willing, interested owner and skilled designer
- Element PBSD much easier than system PBSD and system PBSD is the goal
- Not on a fully probabilistic basis yet

Thank you!