How Advanced Seismic Analysis Maximizes Infrastructure Value

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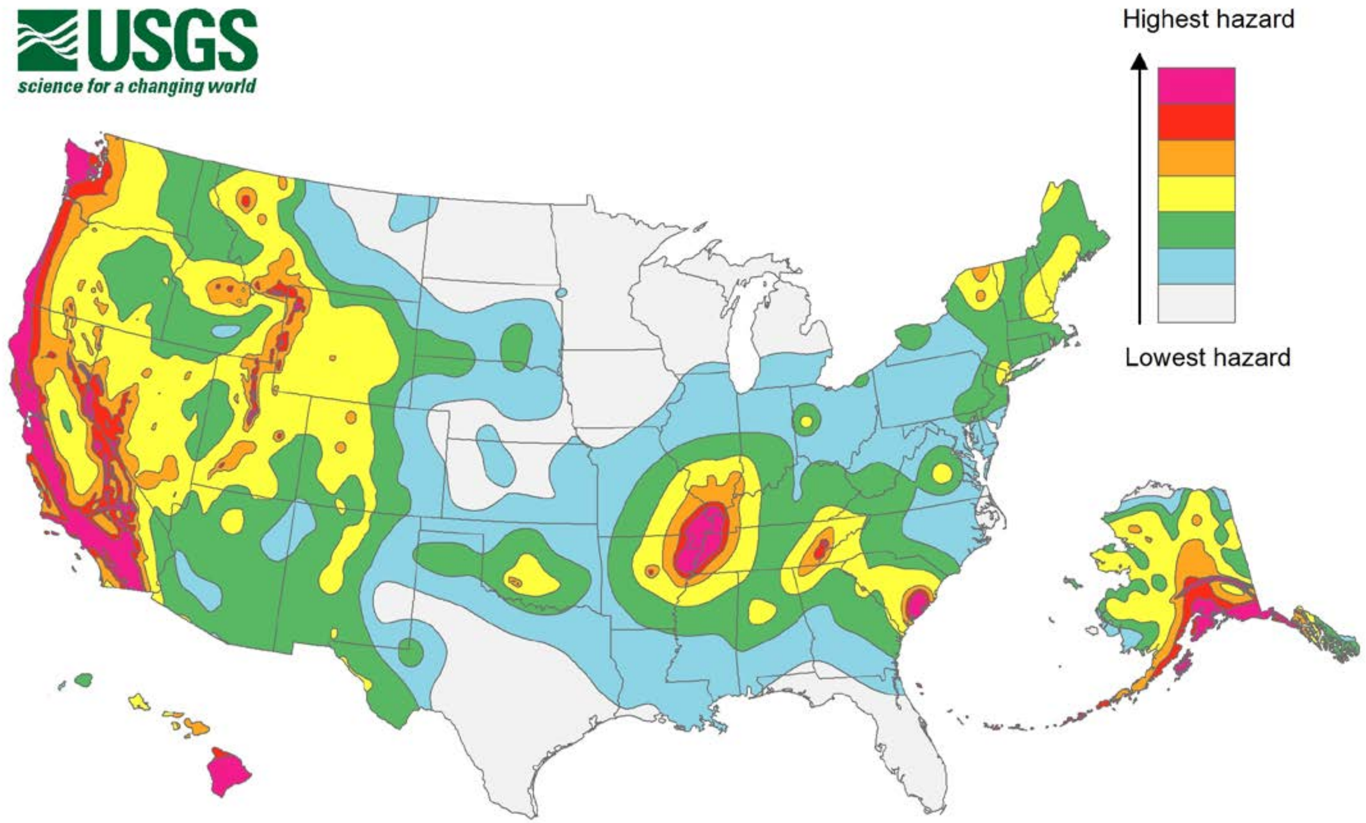
Western Bridge Engineers' Seminar

Outline

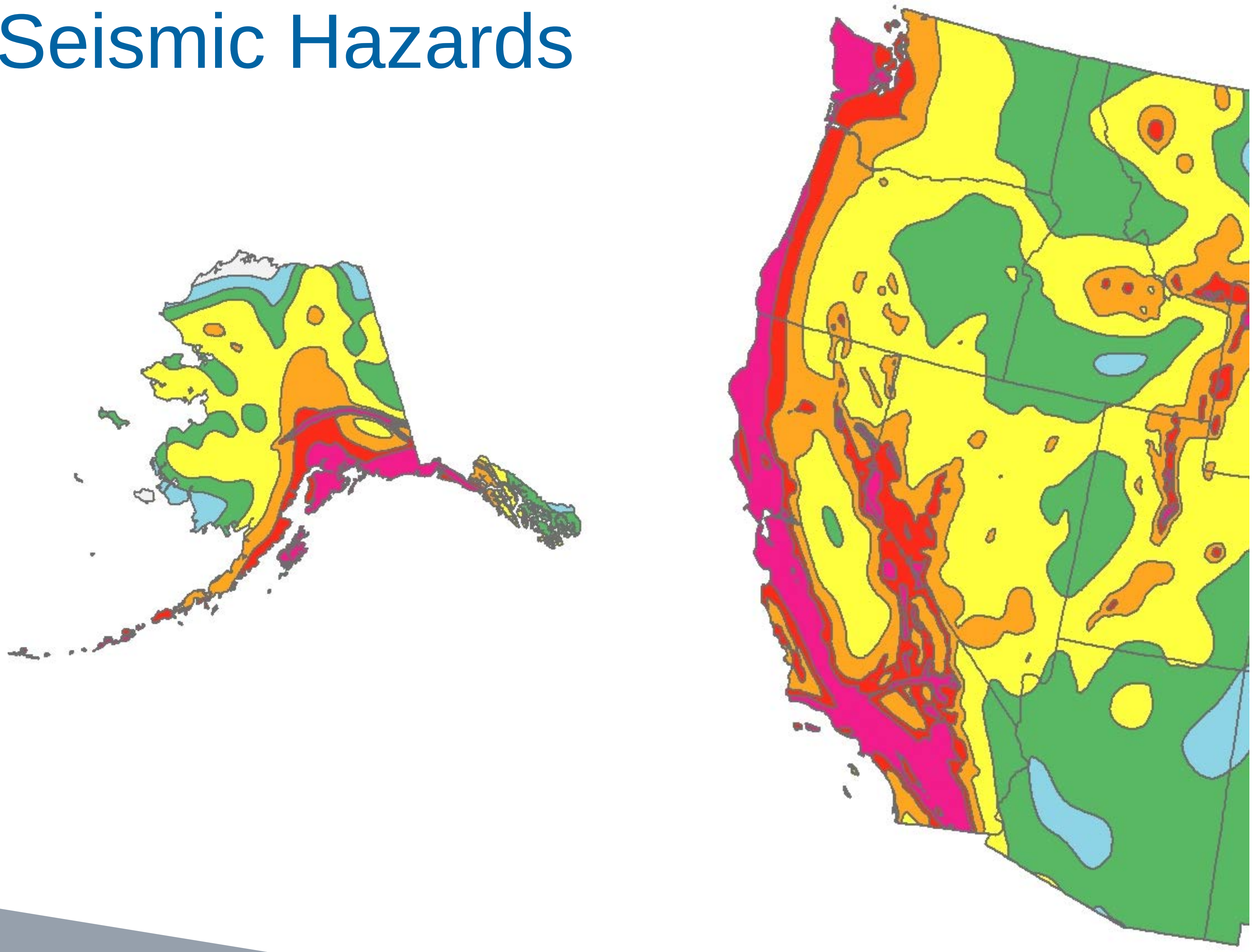
- Seismic Hazards & Risks
- Design Criteria
- Performance-Based Seismic Design
- Analysis Methods
- Project Applications
- Research Developments

Seismic Hazards



- Site Location & Soil Type Based
- Anticipated Ground Motion (Intensity of Shaking)

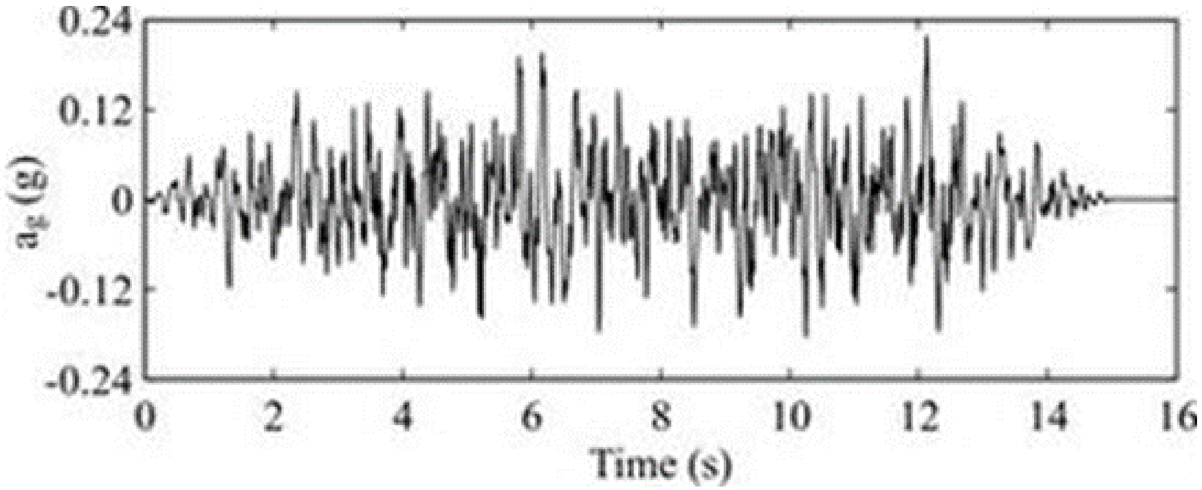
Seismic Hazards



Seismic Hazards

Audience:

- Bridge Seismic Design Experience?
- Personal Seismic Experience:
  - Felt EQ?
  - M6?
  - M7?



Seismic Risks

Risk = Hazard x Vulnerability (Structure Specific)

- Likelihood of Failure
- Danger to Human Life/Property
- Critical Lifeline Compromised?
- Resiliency of Overall Transportation Network

Current Seismic Design Criteria

- New Structure Criteria
  - Most State DOT's: AASHTO LRFD Seismic
  - Life Safety for ~1000 year return period (7%/75 yrs)

Current Seismic Design Criteria

- Existing – Agency Specific
- FHWA Seismic Retrofit Criteria
  - Performance-Based Design (PBD)

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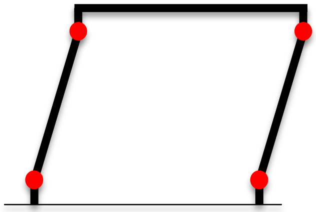
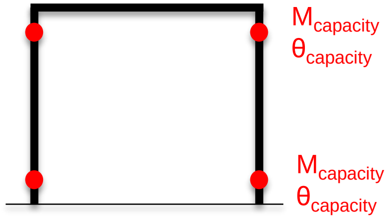
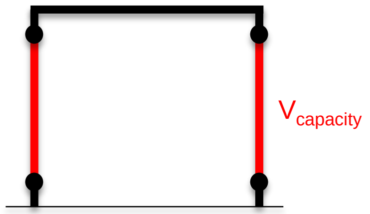
Performance-Based Design (PBD)

- Multiple Design Hazard Levels
  - Select Performance Levels for Specific Hazards
  - Addresses System Risks Directly

Seismic Performance Levels

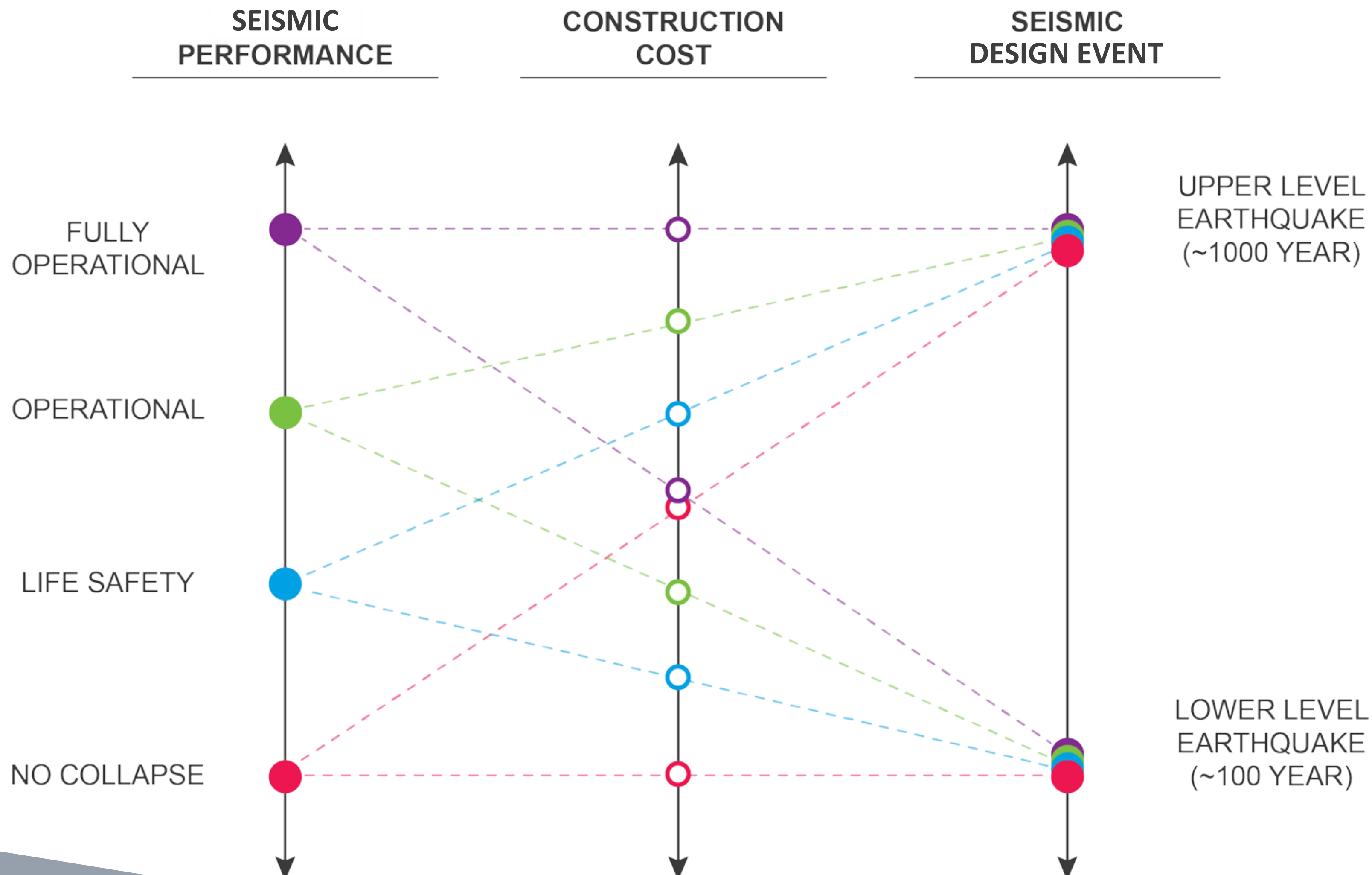
Example Criteria	Fully Operational	Operational	Life Safety	No Collapse
Damage?	Negligible	Minimal (Joints, Bearings)	Significant	Extensive
Safe for Traffic?	Yes	Yes (At Low Speed)	No	No
Repairable to Full Function?	Yes (No Closure)	Yes (Minimal Closure)	Maybe	No
Immediately Functional?	Yes, Fully	Emergency Vehicles Only	No	No

Pillars of Performance-Based Design (PBD)

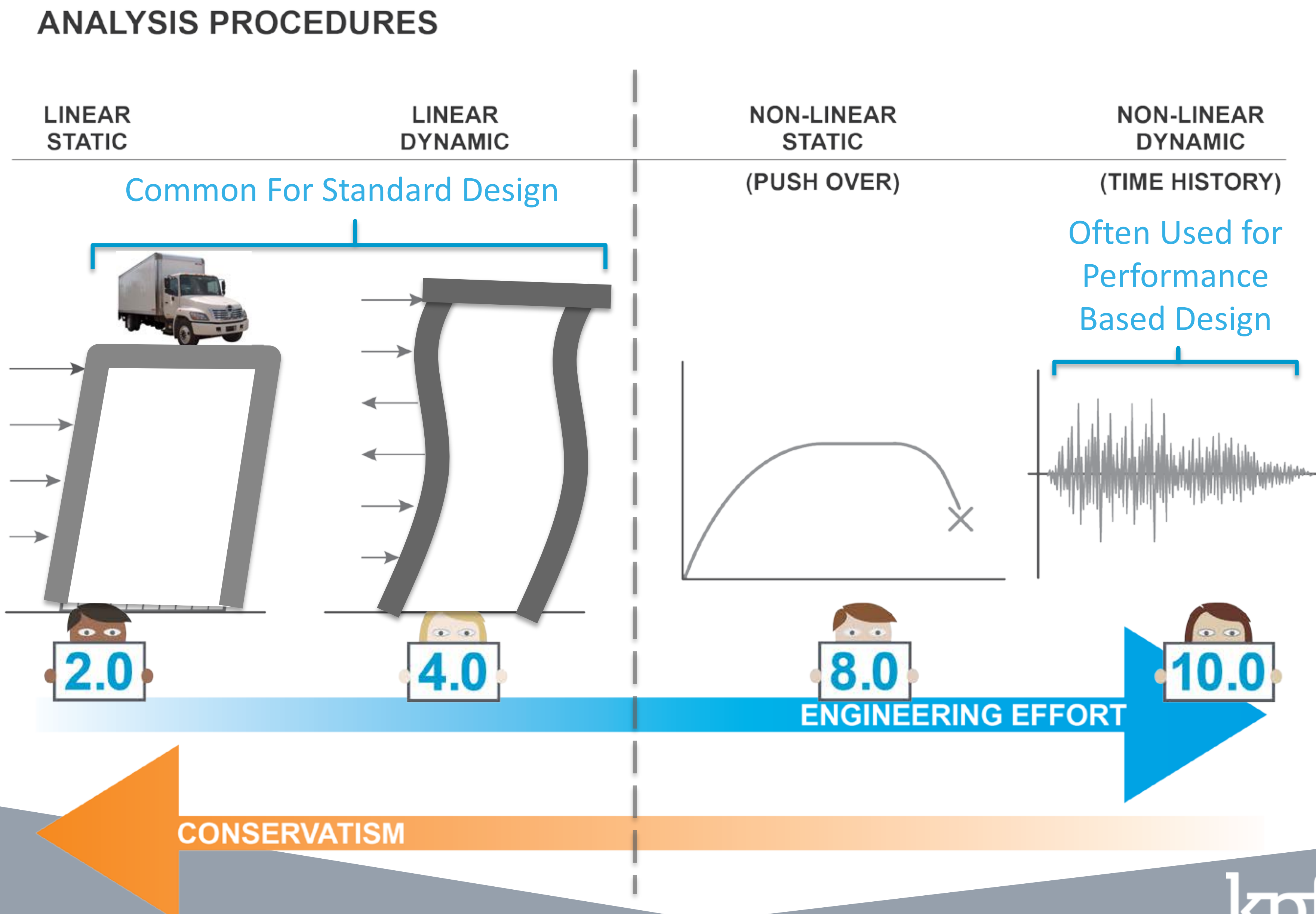
1. Select a ductile mechanism	
2. Establish minimum strength and required deformation capacity for performance objective	
3. Protect other components through capacity design	

PBD: Performance Objectives

Construction Cost Comparison



Advanced Analysis



Why Use PBD + Advanced Analysis?

- Better Engineering
  - "Lean" Design
  - Non-Prescriptive
  - Archaic Construction
  - Retrofit Applications

- Better Resiliency
  - Critical Lifeline Infrastructure
  - Longer Service Life Structures

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PBD + Advanced Analysis

- Client Quote After Retrofit Project:

"I spent $60,000 and saved over $3 million. Why don't we always do this?"
(This particular project was a great candidate for PBD and Non-Linear Time History Analysis; and it showed)

NE 10th Ave. Bridge over Whipple Creek

- Clark County / Vancouver, WA
- 3-span, 450 ft. Total Length
- Continuous Steel Plate Girders
- Mechanically Stabilized Earth (MSE) Abutments
- Stone Column Ground Improvements

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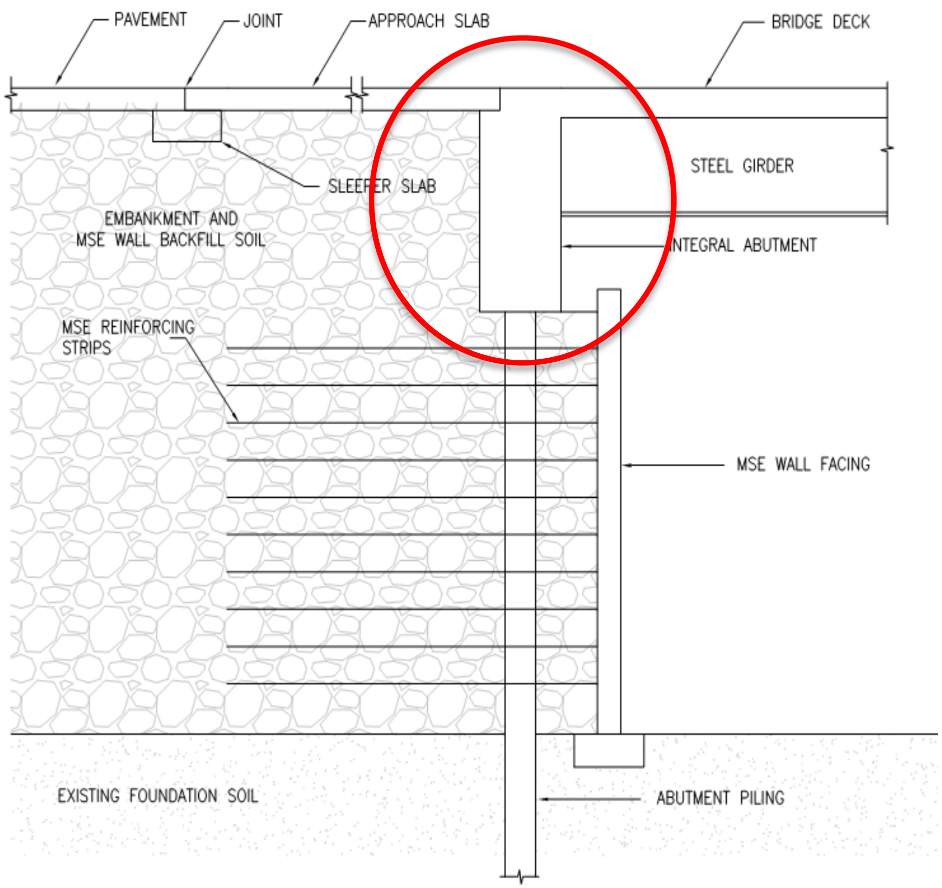
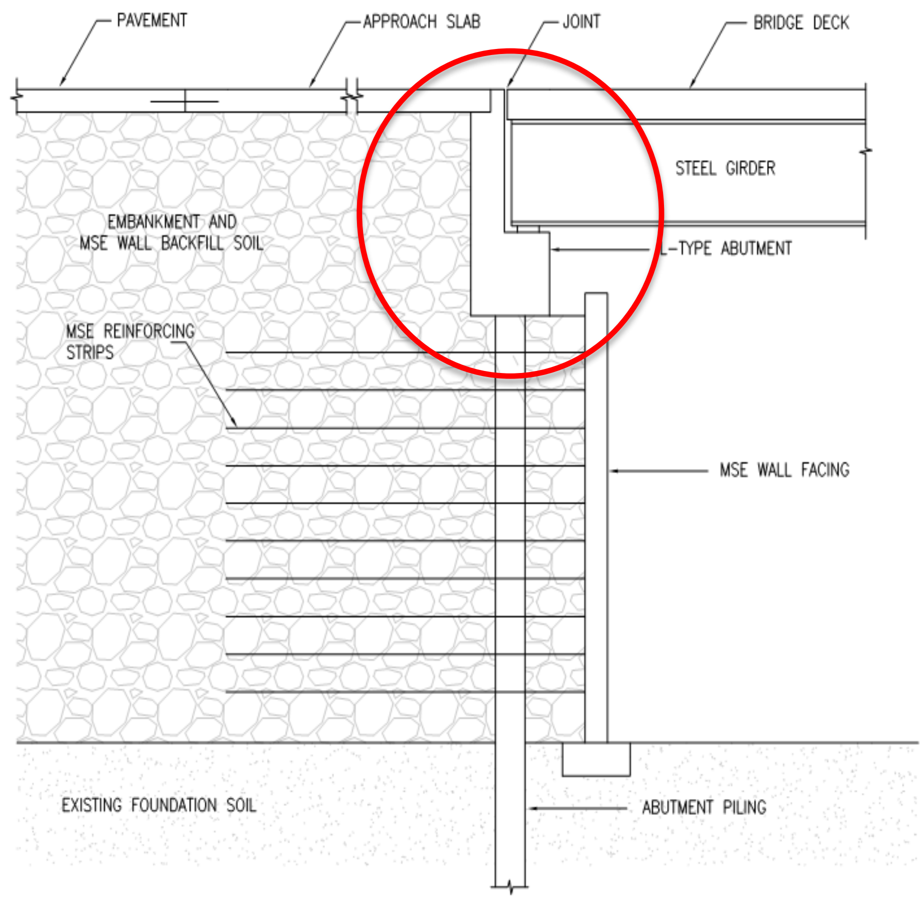
NE 10th Ave. Bridge

- Performance-Based Design
- Non-Linear Time History Analysis - Perform 3D
- Soil-Structure Interaction w/ MSE - LUSAS
- Optimized Substructure Design

Substructure Optimization



Integral Abutment



Traditional L-type Abutment

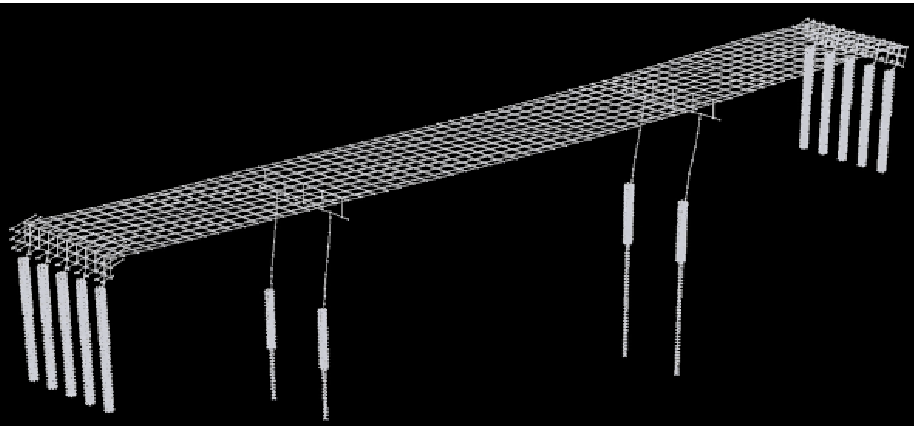
Alternatives Analysis

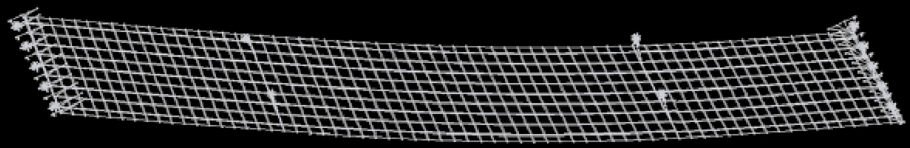
	Abutment Type		
	Integral	Semi-Integral	L-Type
Initial Substructure Construction Costs[1]	0%	+25%	+25%
Maintenance Costs[2]	Low	Medium	High

[1] Initial construction costs are expressed as % increase over that for an integral abutment design
[2] Maintenance costs were not quantitatively evaluated

NE 10th Ave. Bridge

- Performance
  - End Bents/Abutments & End Panels Fully Engaged
  - Interaction w/ MSE Walls Extensively Researched
  - Interior Bents Optimized
  - Non-Linear Time History Analysis





NE 10th Ave. Bridge

- Integral Abutments (Joint-Less Bridge)
  - Highly Efficient, Minimized Substructure Dimensions
  - Reliable Seismic Performance
  - Minimal Maintenance
  - Approx. 25% Lower Substructure Cost

PBD+ Advanced Analysis

- Explicitly Balances Risks vs. Costs

- Life-Cycle Costs
  - Seismic Risk Considerations

- Benefits:
  - Performance Reliability
  - Flexibility to Match Owner Priorities
  - Less Conservative
  - Potentially Major Construction Cost Savings

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PBD+ Advanced Analysis

- Challenges:
  - Technical Knowledge Requirements
  - Computational Demands
  - Analysis Time/Design Schedule Impacts
  - Design Time & Cost = Investment

PBD+ Advanced Analysis

- When Investment Makes the Most Sense:
  - High Seismic Hazard & Risk
  - Critical Lifelines
  - Atypical Site/Soil Conditions
  - Sensitive Existing Infrastructure
  - Long/Multi-Span Structures

- When it Likely Doesn't:
  - Low Seismic Hazard & Risk
  - Low-Priority Infrastructure
  - Standard, Single Span Structures

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Existing Structures

- Determine Mechanisms
  - Ductile vs. Brittle
  - Hinge Locations Vary

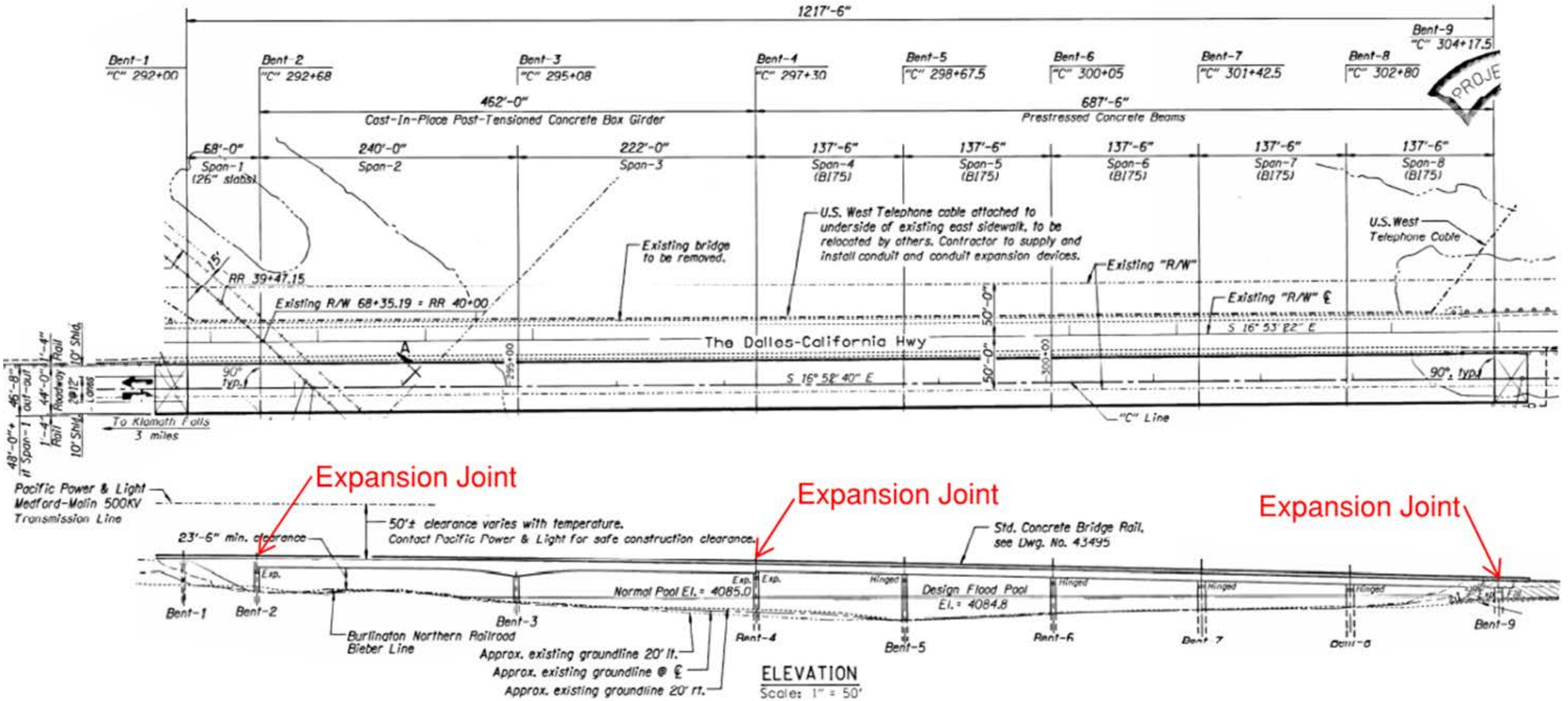
- Foundation Rocking?

- Require Performance and Mechanisms per New Bridge Design?

US97 Klamath River Bridge Retrofit, OR

- ODOT
- FHWA Retrofitting Manual
- 1993 Design
- Drilled Shaft Columns
- Diatomaceous Silt Soil, depth varies widely
- 8 spans
- >1200' Long

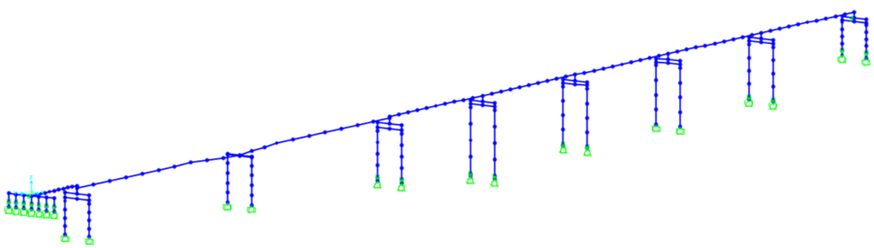
US97 Klamath River Bridge Retrofit



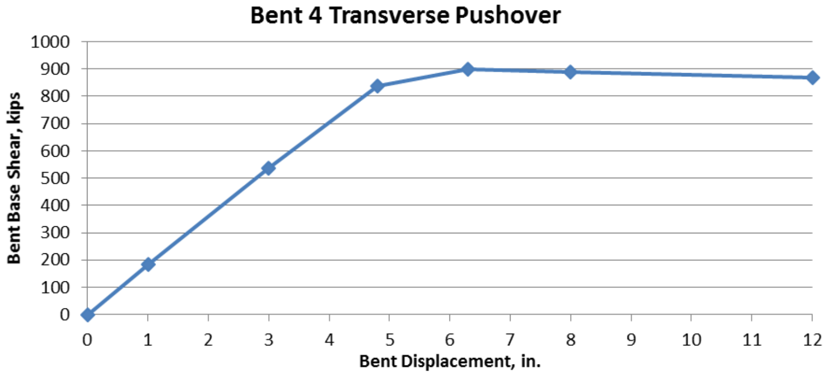
- 3 Superstructure Types: P/S Slab (Span 1), Cont. Haunched P/T Box Girder (Spans 2-3), P/S Bulb-I (Spans 4-8)
- Highly Variable Substructure Stiffness (Soil Strength Governed)

US97 Klamath River Bridge Retrofit

- Analysis – per ODOT Criteria:
- Linear Multi-Modal Response Spectrum Analysis
  - SAP2000 Demand Model
  - Abutment Soil Springs
  - Bent Foundations per Lpile
  - <u>Iteration to Capture:</u>
    - Joint Gap/Closure
    - Bent-by-Bent Soil-Structure Behavior



- Separate Nonlinear Pushover Models
  - Lpile Nonlinear Capacity Models
  - Bent-by-Bent Evaluation



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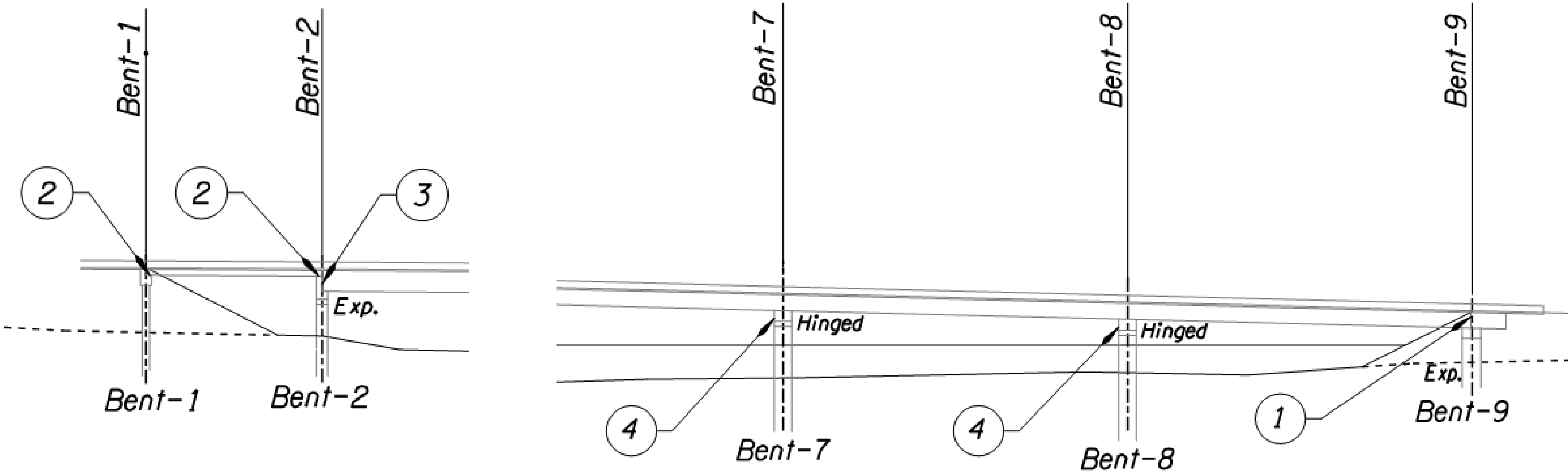
US97 Klamath River Bridge Retrofit

- Retrofits per Design Criteria:



REFERENCE NOTES:

1. Add bumper blocks.
2. Slab connection strengthening.
3. Shear lug strengthening.
4. Cross beam strengthening.

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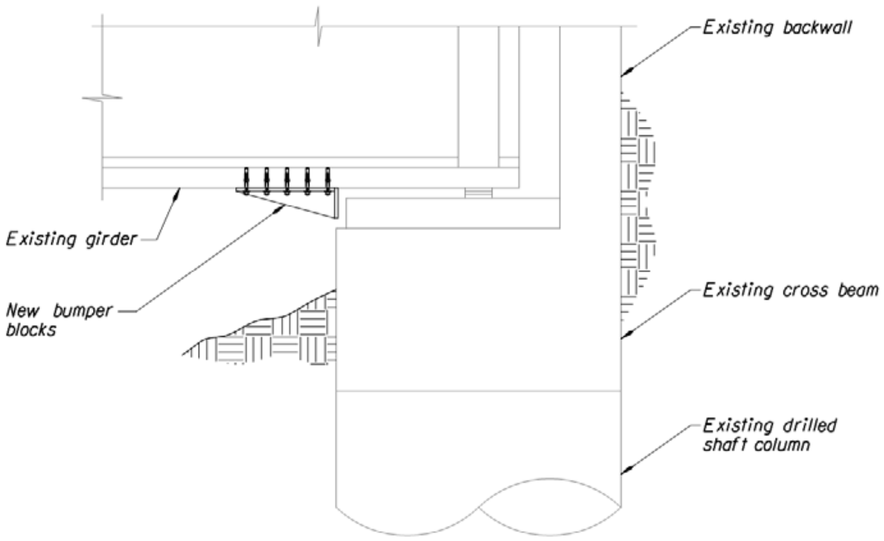
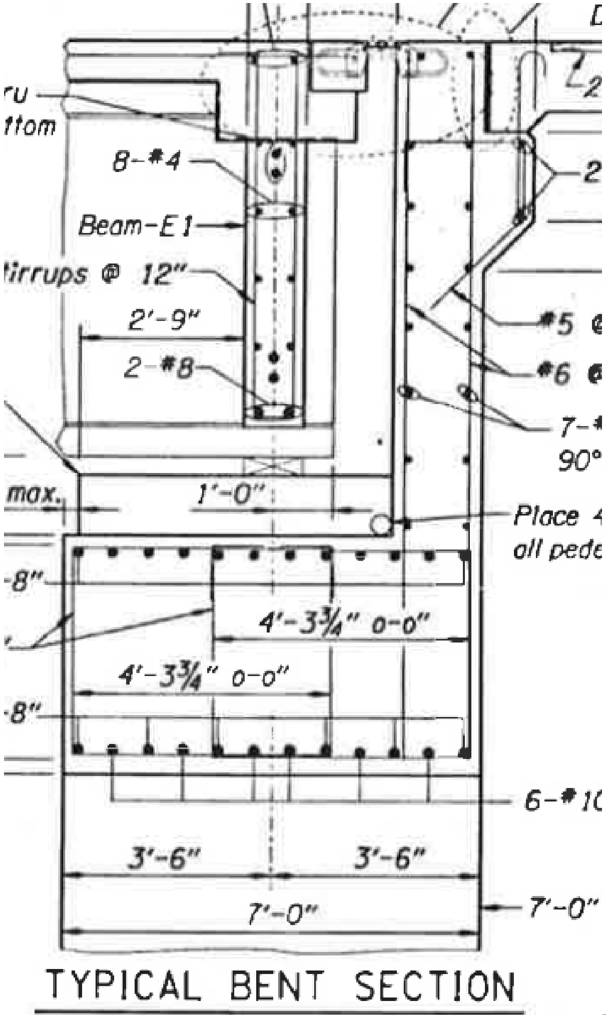
US97 Klamath River Bridge Retrofit

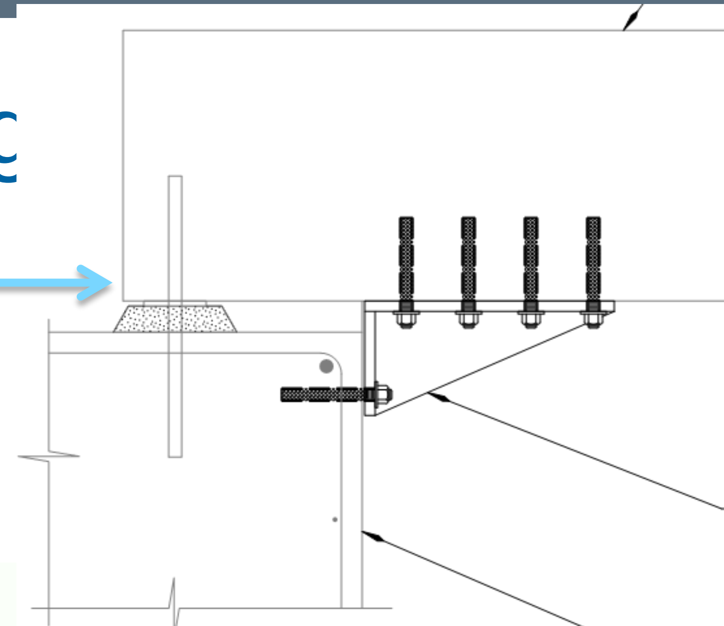
1) Bent 9 Bumper Blocks





US97 Klamath River Bridg

2) Span 1 (Slab) Connection Strengthening

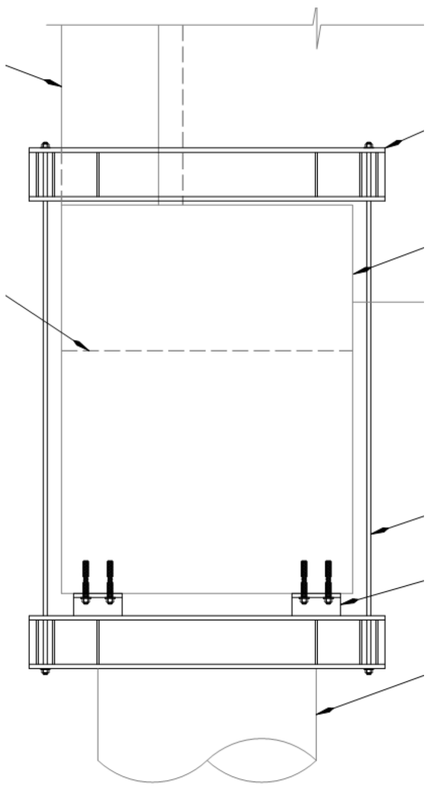


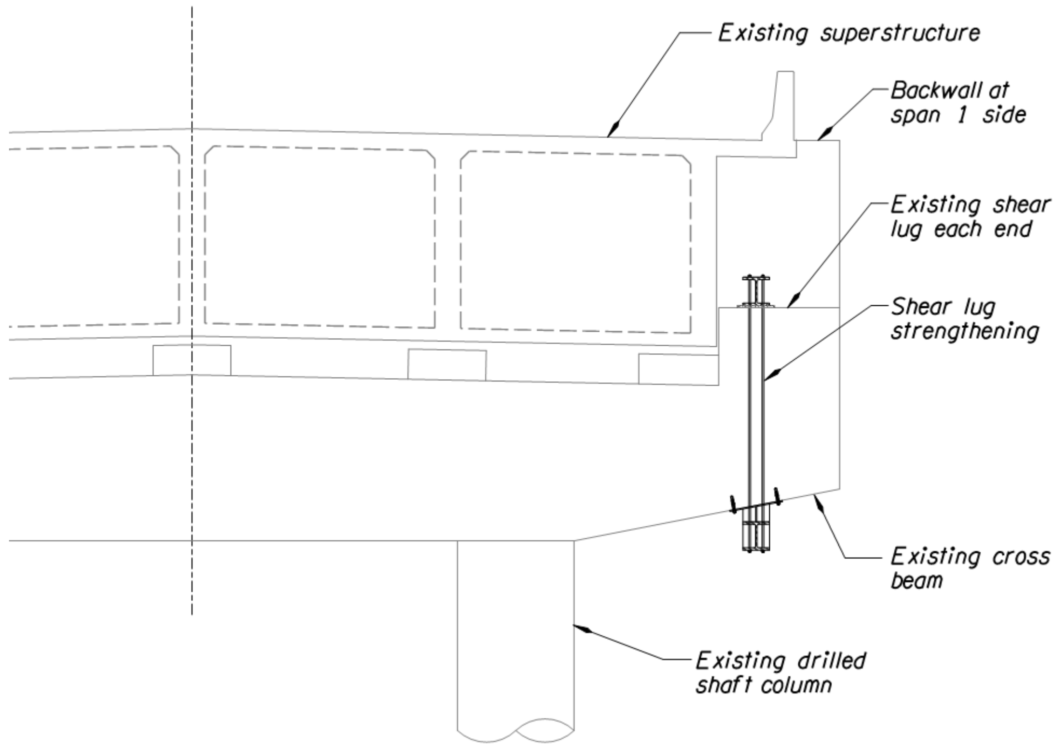
3) Bent 2 Shear Lug Strengthening

US97 Klamath River Bridge Retrofit

3) Bent 2 Shear Lug Strengthening

- External Post-tensioning



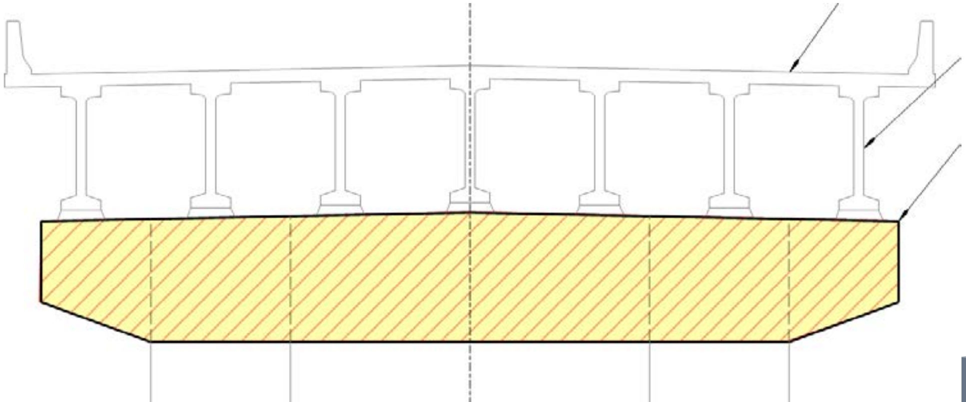


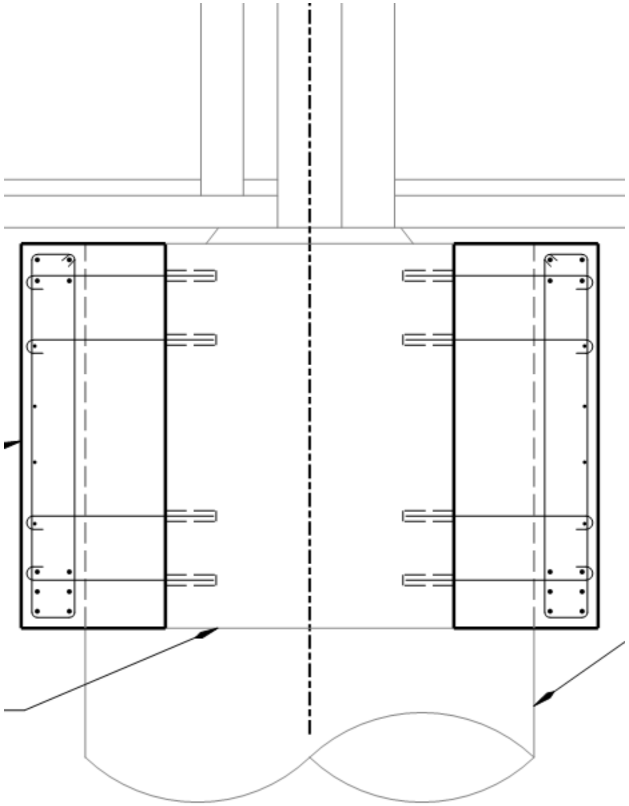
BENT 2 ELEVATION

US97 Klamath River Bridge Retrofit

4) Bent 7 & 8 Cross Beam Strengthening

- Further Investigation Recommended (Design Exception?)





US97 Klamath River Bridge Retrofit

- Outcome:
  - Local Strengthening Only
  - No Temporary Bridge Req'd
  - No Additional Shafts
  - No In-water Work
  - Significant Savings

- Estimated Costs:
  - Retrofit Cost < $500,000
  - ~30% of Preliminary Estimate

US97 Klamath River Bridge Retrofit

- Proposed ODOT Retrofit Criteria Revisions:
  - Allow Evaluation of Footing Rocking
  - Allow Evaluation of Bent Cap & Footing Hinging
- Reduce Conservatism to Maximize Value

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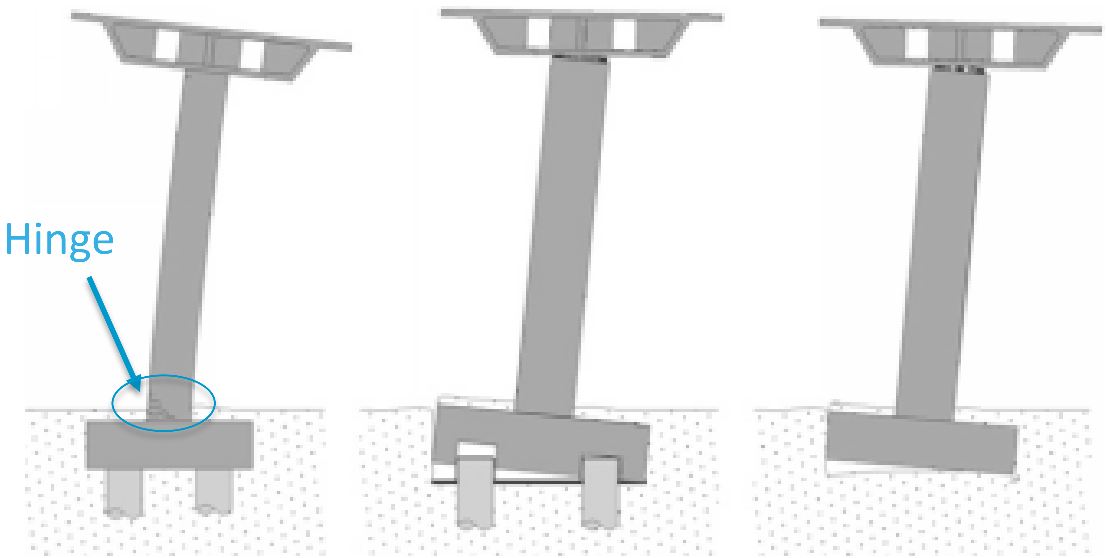
Foundation Rocking Research

- Currently Not Allowed per AASHTO & FHWA
- Potentially Beneficial Seismic Behavior



Fixed Base | Pile Rocking | Shallow Foundation Rocking

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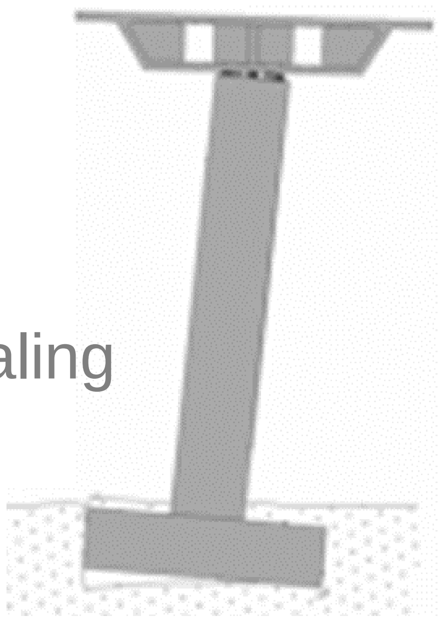
Foundation Rocking Research

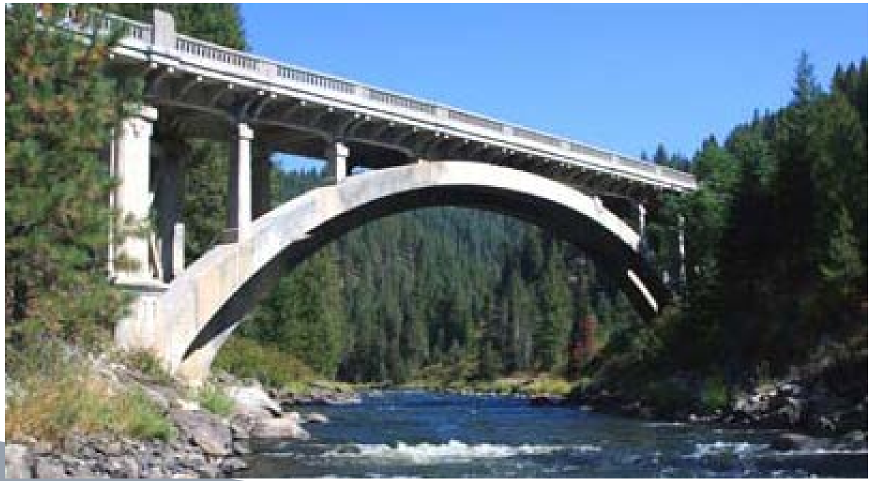
Current Research at Portland State University assisted by KPFF

- Goal: Aid Development of Evaluation & Acceptance Criteria for Foundation Rocking
- Non-Linear Time History Analyses
  - 12 Motions x 8 Scaled Hazards
  - Multi-Directional
  - Non-linear Soil Springs
  - Vary Dim’s, Soil Prop’s, Vert. Loads, Scaling
- Currently Pursuing Publication



Summary

- Advanced Analysis = Investment (when appropriate)
  - More Engineering Effort → Less Const. Cost & Time
- Tools & Techniques are Readily Available
- Resilience Planning is Key for Decision Making
- Field is Constantly Evolving w/ Research
- Expectations & Criteria Need Periodic Review and Update



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Acknowledgements

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Thank You!

Questions?

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