Portland State University

Department of Civil and Environmental Engineering
Maseeh College of Engineering & Computer Science

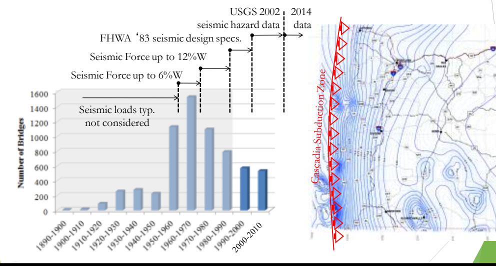
Achieving Operational Seismic Performance with Ductile Fuse Retrofit

Peter Dusicka, PhD, PE - Associate Professor

Ramiro Bazaez, PhD and Mike Miotke, PE - former graduate students

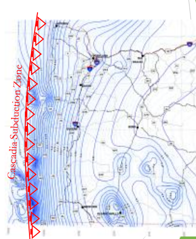
Federico Santa Maria Technical University | WSP (Parsons Brinckerhoff)

Oregon Hwy. Bridges and EQ Hazard

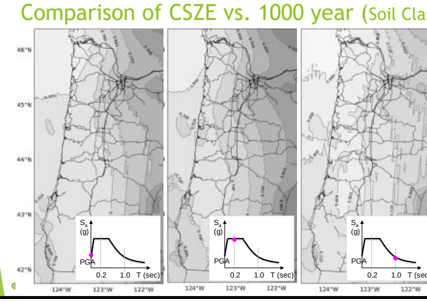


Oregon's Dual Seismic Performance

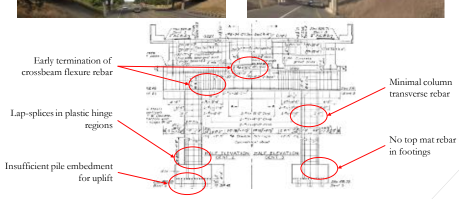
	Ground Motion	Design criteria
Life-safety Criteria	1000 year EQ (7% probability of exceed. in 75 years)	Mainly following AASHTO Guide Spec.
Operational Criteria	Full rupture CSZ based on 2014 USGS hazard	More stringent maximum conc. & reinf. strains
	… on and West of US97	



Comparison of CSZE vs. 1000 year (Soil Class B)

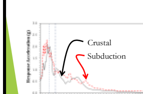


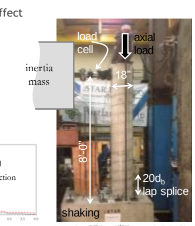
Potential Issues Beyond Phase 1 Retrofit

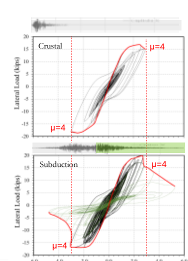


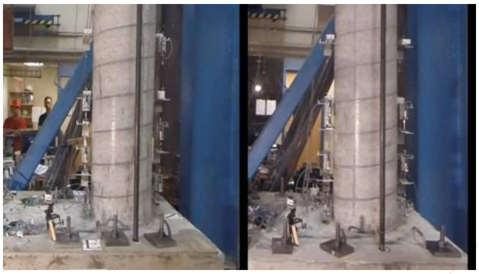
CSZE Duration Influence

- Dynamic effect on bridge column

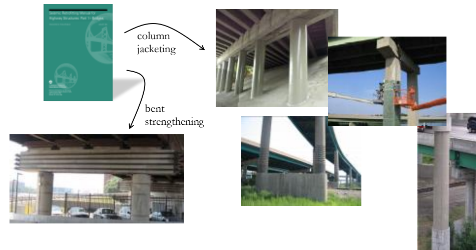






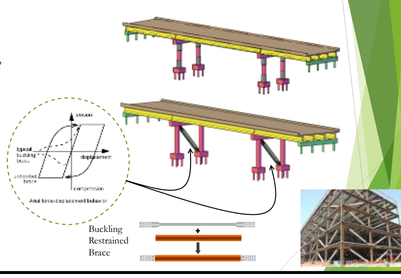


Conventional Retrofit Strategies

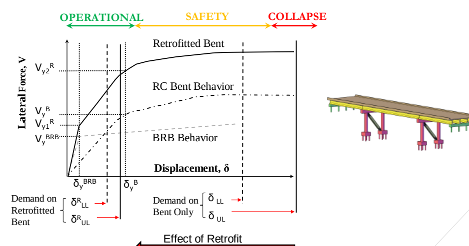


Performance Based Approach to Retrofit

- Conventional retrofit
  - Safety … yes
  - Operational … maybe?
- Fuse based retrofit
  - Operational … focus!
  - Safety … yes.
- Role of the fuse
  - NOT for strength
  - stiffness and ductility
  - replaceability

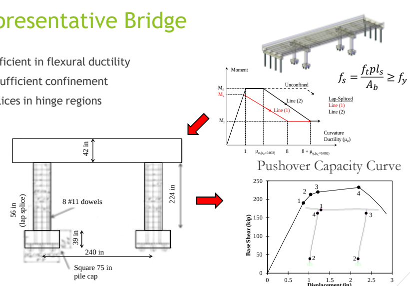


Generic Pushover Response of Bent

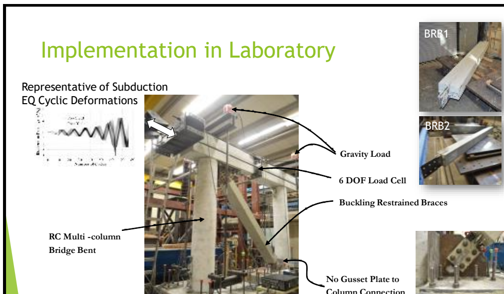


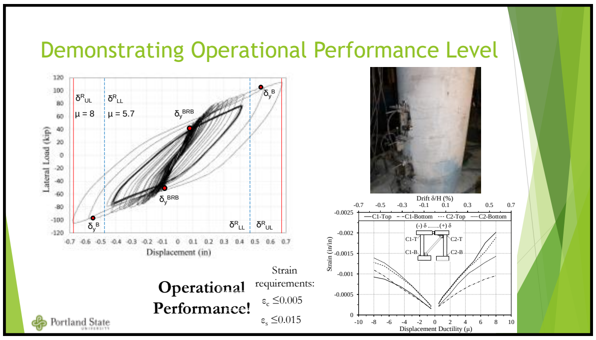
Representative Bridge

- Deficient in flexural ductility
- Insufficient confinement
- Splices in hinge regions



Implementation in Laboratory




Demonstrating Operational Performance Level
Lateral Load (kip)
Displacement (in)
μ = 8
μ = 5.7
Operational Performance!
Strain requirements:
ε_c ≤0.005
ε_s ≤0.015
Drift δ/H (%)
Strain (in/in)
Displacement Ductility (μ)
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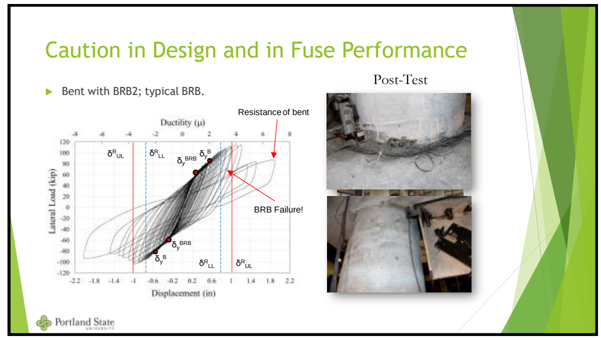
Caution in Design and in Fuse Performance
Bent with BRB2; typical BRB.
Post-Test
Ductility (μ)
Resistance of bent
BRB Failure!
Lateral Load (kip)
Displacement (in)
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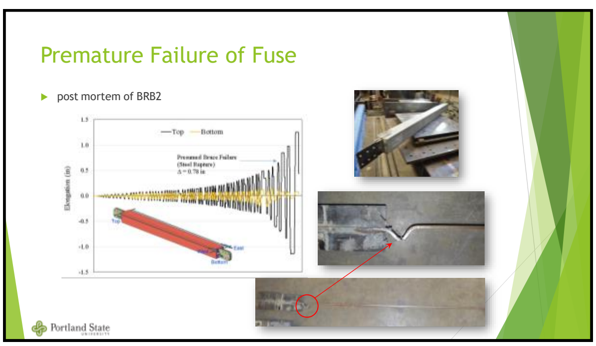
Premature Failure of Fuse
post mortem of BRB2
Top
Bottom
Elongation (in)
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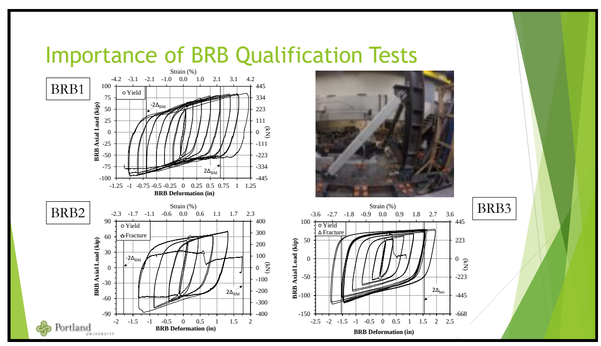
Importance of BRB Qualification Tests
BRB1
BRB2
BRB3
Strain (%)
BRB Axial Load (kip)
BRB Deformation (in)
Yield
Fracture
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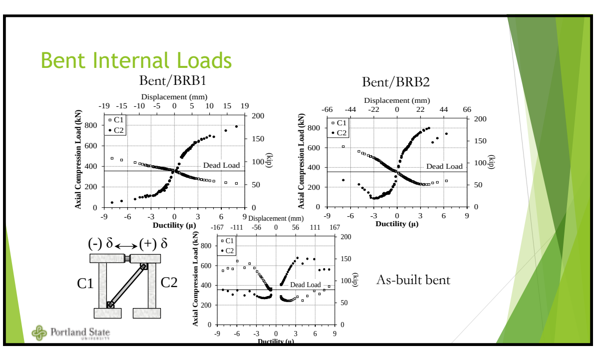
Bent Internal Loads
Bent/BRB1
Bent/BRB2
Displacement (mm)
Axial Compression Load (kN)
Ductility (μ)
Dead Load
C1
C2
(-) δ
(+) δ
As-built bent
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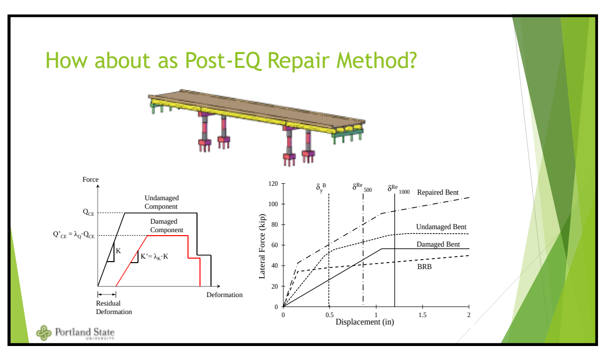
How about as Post-EQ Repair Method?
Force
Undamaged Component
Damaged Component
Residual Deformation
Deformation
Lateral Force (kip)
Displacement (in)
Repaired Bent
Undamaged Bent
Damaged Bent
BRB
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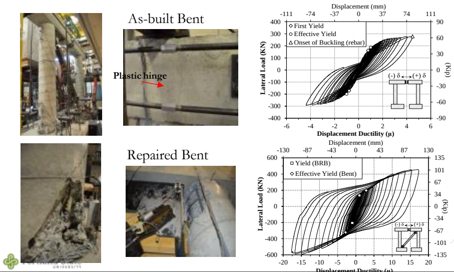
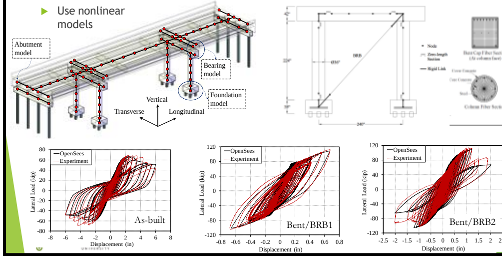
Bent Damage and Repaired Bent Results



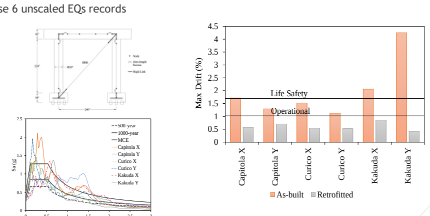
Numerical Model Assessment

- Use nonlinear models



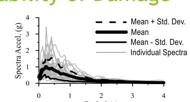
Operational Performance

- use 6 unscaled EQs records

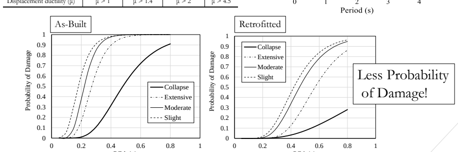


Significantly Reduced Probability of Damage

- Use 30 subduction EQs
- Damage states



EDP	Damage States			
	Slight	Moderate	Extensive	Collapse
Displacement ductility (μ)	μ > 1	μ > 1.4	μ > 2	μ > 4.5



Retrofit Viability Case Study

- Objective:
  - evaluate the viability of fuse based structural retrofit measure with more conventional retrofit methods while considering ODOT's dual performance criteria
  - compare achieving performance objectives and estimated costs
- Sample selected 3 bridges of similar size:
  - varying skew, superstructure-substructure connectivity
  - round columns and square columns
  - moderate seismic hazard (1000 year for life safety, 500 year operational)
- Conventional seismic retrofit measures
- Ductile fuse based retrofit measure incorporating BRBs

On 99W over creek (1954)

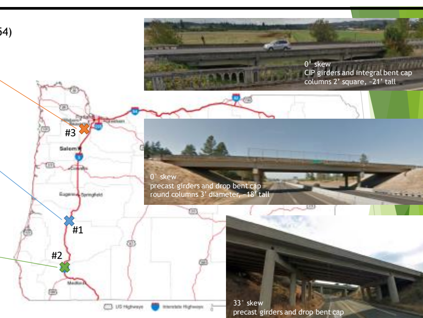
	500-yr	1,000-yr
PGA	0.18	0.26
S_S	0.44	0.61
S_1	0.15	0.23

Road Over I-5 (1966)

I-5	500-yr	1,000-yr
PGA	0.13	0.22
S_S	0.31	0.53
S_1	0.14	0.25

SB I-5 over road (1967)

	500-yr	1,000-yr
PGA	0.13	0.22
S_S	0.30	0.53
S_1	0.14	0.25



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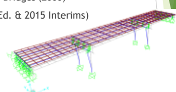
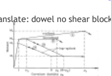
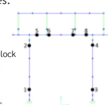
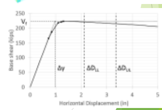
Analyses Methods

- Practical design guidelines used:
  - ODOT Bridge Design & Drafting Manual
  - FHWA Seismic Retrofitting Manual for Highway Structures: Part 1 – Bridges (2006)
  - AASHTO Guide Specifications for LRFD Seismic Bridge Design (2nd Ed. & 2015 Interims)
- Demand analyses using elastic multimodal analyses:
  - lower level, LL → Operational 500 year return ($\Delta D_{LL} < \Delta_y$)
  - upper level, UL → Life-safety 1000 year return ($\Delta D_{UL} < \Delta_C$)
- Capacity assessment using pushover analyses:
  - pushover analyses for Δ_y and Δ_C
  - abutment modeling
    - transverse free to translate: dowel no shear block
    - longitudinal









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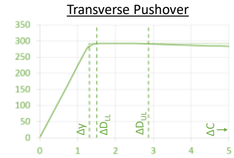
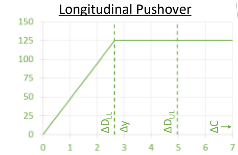
Assessment of Example Bridge #2

Transverse Pushover



Longitudinal Pushover



Bridge #2 - Existing						
Axis	ΔD_{LL}	Δy	$\Delta D_{LL} \leq \Delta y$	ΔD_{UL}	ΔC	$\Delta D_{UL} \leq \Delta C$
Trans.	1.51”	1.31”	FAIL	2.87”	6.37”	PASS
Long.	2.63”	2.65”	PASS	4.96”	7.00+”	PASS

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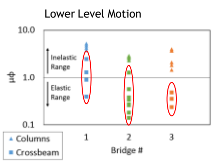
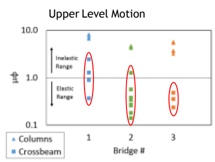
Hinge Ductility Demands





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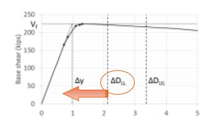
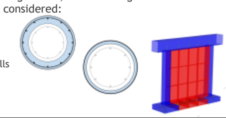
Conventional Retrofits

- Retrofit goals:
  - Achieve Operational criteria
  - Reduce ΔD_{LL}
  - Bent stiffening and strengthening
  - NOT necessarily ductility enhancement (i.e. wrapping columns with FRP)



- Using guidance of FHWA Seismic Retrofitting Manual, the following retrofit measures for bent stiffening and strengthening were considered:
  - Concrete column overlay
  - Steel column jacketing
  - Full-height reinforced concrete infill walls



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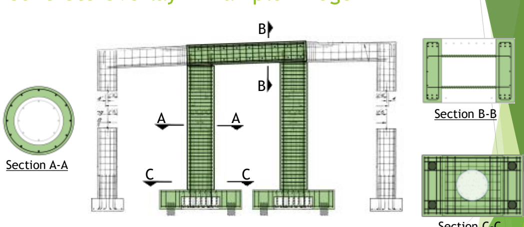
Concrete Overlay – Example Bridge 2



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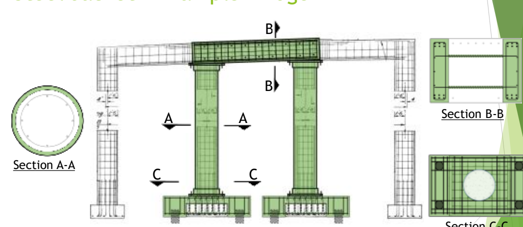
Steel Jacket – Example Bridge 2



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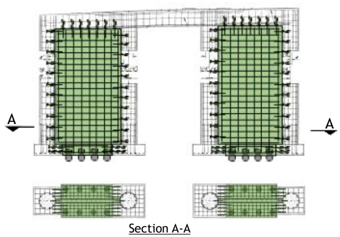
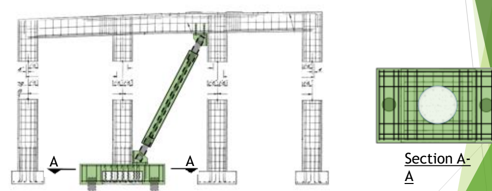
Concrete Infill Wall – Example Bridge 2

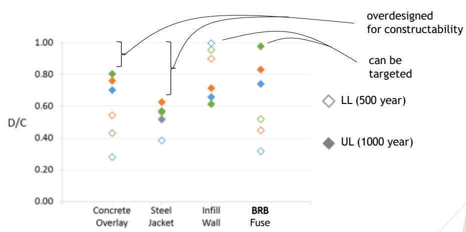


BRB Fuse – Bridge #2

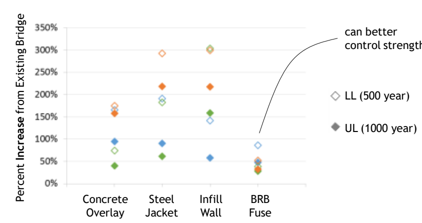
Bridge 2:



Performance Comparison D/C Ratio

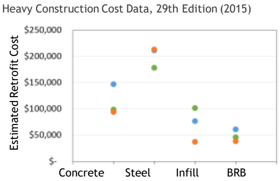


Base Shear Comparison – Transverse

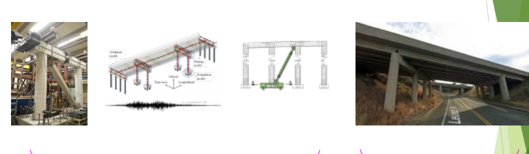


1st Pass Estimated Retrofit Cost

- Structural work estimates only
  (not accounting for mobilization, site prep., traffic control …)
- 2015 ODOT Bridge Cost Data
- RSMeans Heavy Construction Cost Data, 29th Edition (2015)



Bottom Line of Ductile Fuse Seismic Retrofit



TODAY
Viable approach for achieving operational goals!

NEXT STEP
Find a real bridge demonstration?