Seismic Criteria Development

SR 520 Bridge Replacement Program

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U.S. Department of Transportation
Federal Highway Administration

Washington State Department of Transportation

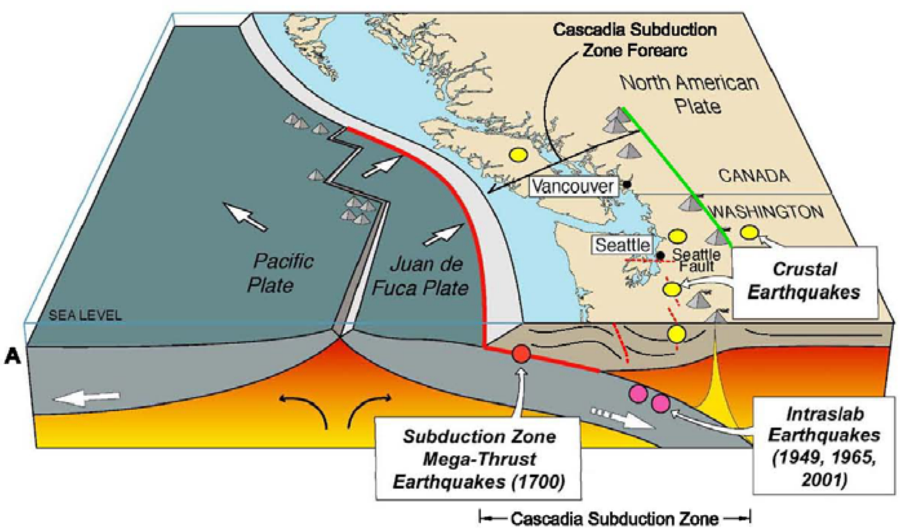
HDR

Together We Are Better

Project Location

Project Seismic Hazard

- Cascadia Subduction Zone
  - Interplate Mega-Thrust Earthquakes - M_{Max} = 9.2
  - Intraslab Earthquakes - M_{Max} = 7.5



TYPICAL GEOLOGIC CROSS SECTION

Not to Scale

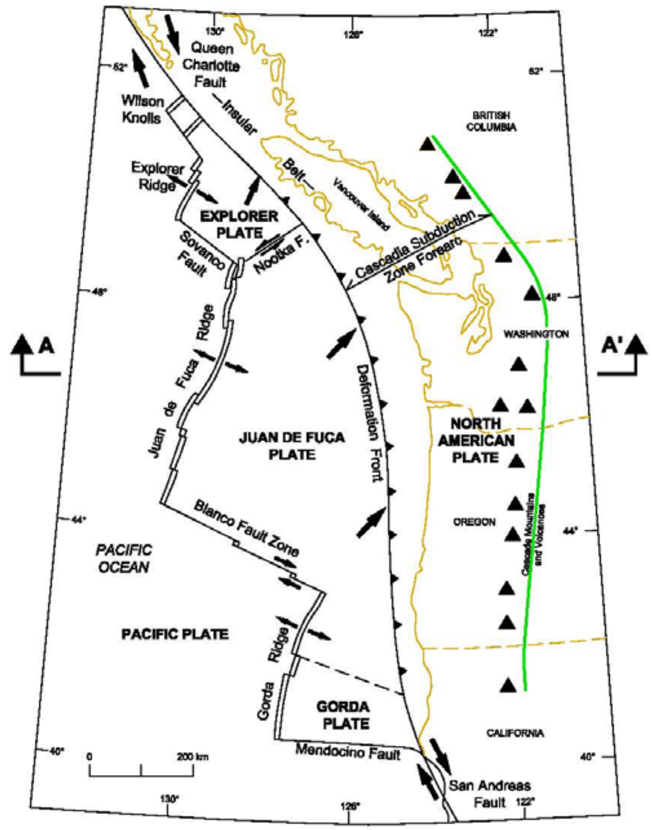


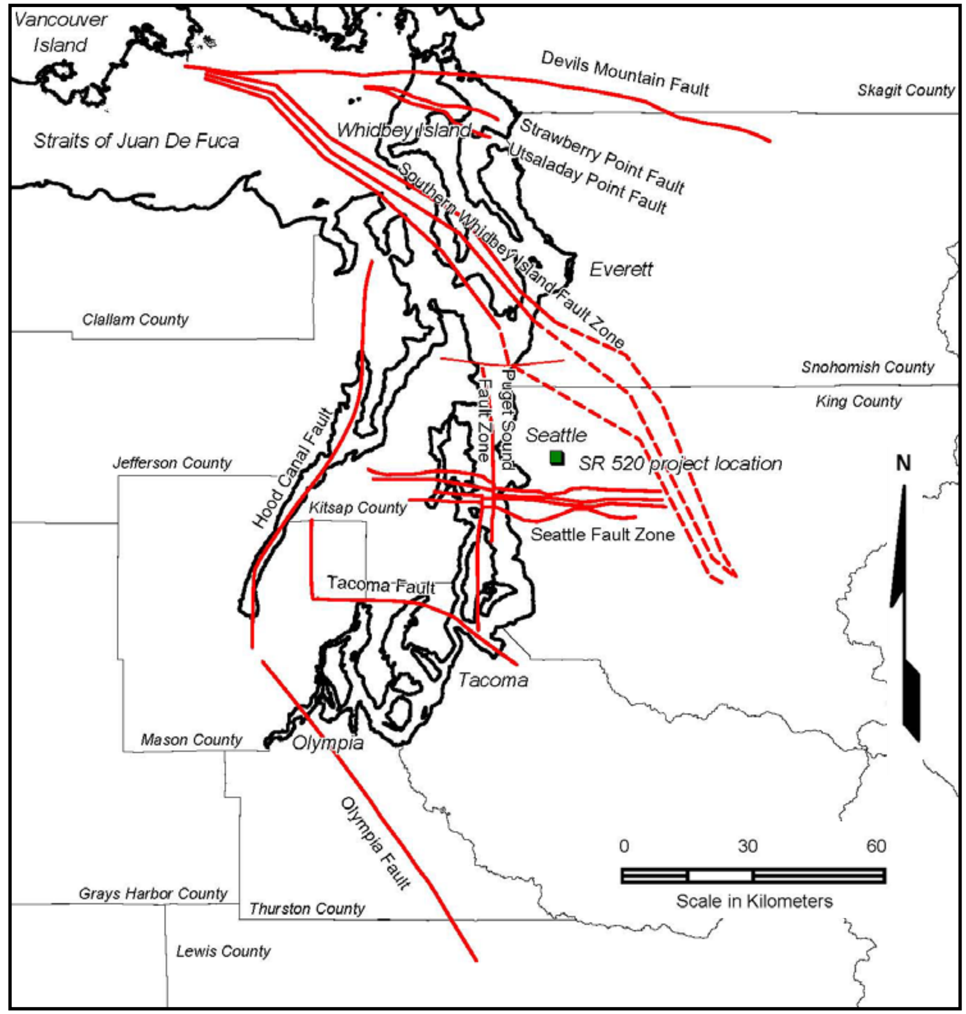
PLATE BOUNDARIES

LEGEND

A — Typical Geologic Cross Section Location

Puget Sound Region Seismic Setting

- Numerous crustal faults
- Significant sources:
  - Seattle Fault Zone (Less than 6 miles from the SR 520 Project)
  - South Whidbey Island Fault Zone

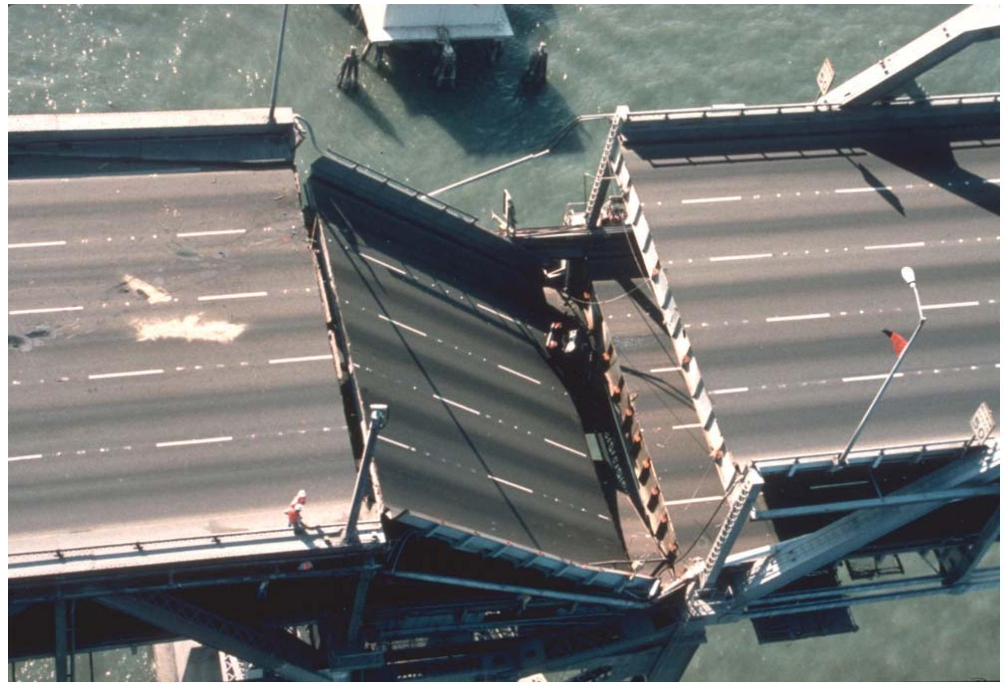


Essential Bridge Designation

- In October 2009 WSDOT designated the mainline bridges on the SR 520 corridor as “essential” bridges.
- WSDOT wanted to ensure a reliable lake crossing after the design earthquake event
- I-90 bridges across Lake Washington were not designed to current seismic standards
- Essential bridges are not within the scope of the AASHTO guide specifications

Essential Bridge Criteria Key Concepts

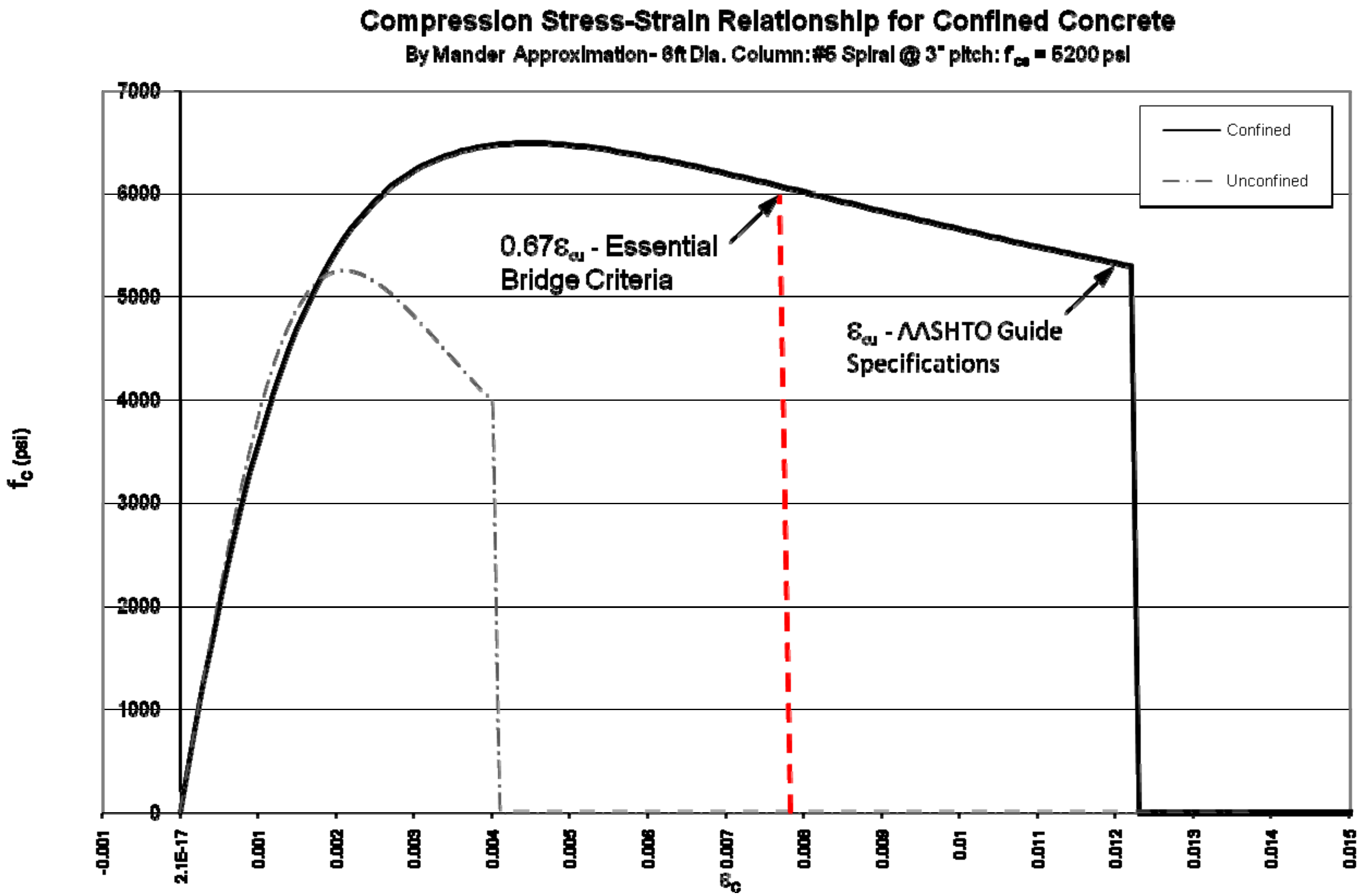
- Applicable to conventional bridges only
- Performance objective is to be capable of essential vehicle service immediately after the 1000 year return period event.
- Requires site specific hazard and ground motion response analysis
- Places more stringent limits on concrete and steel strains
- Considers vertical effects of ground motion on the superstructure



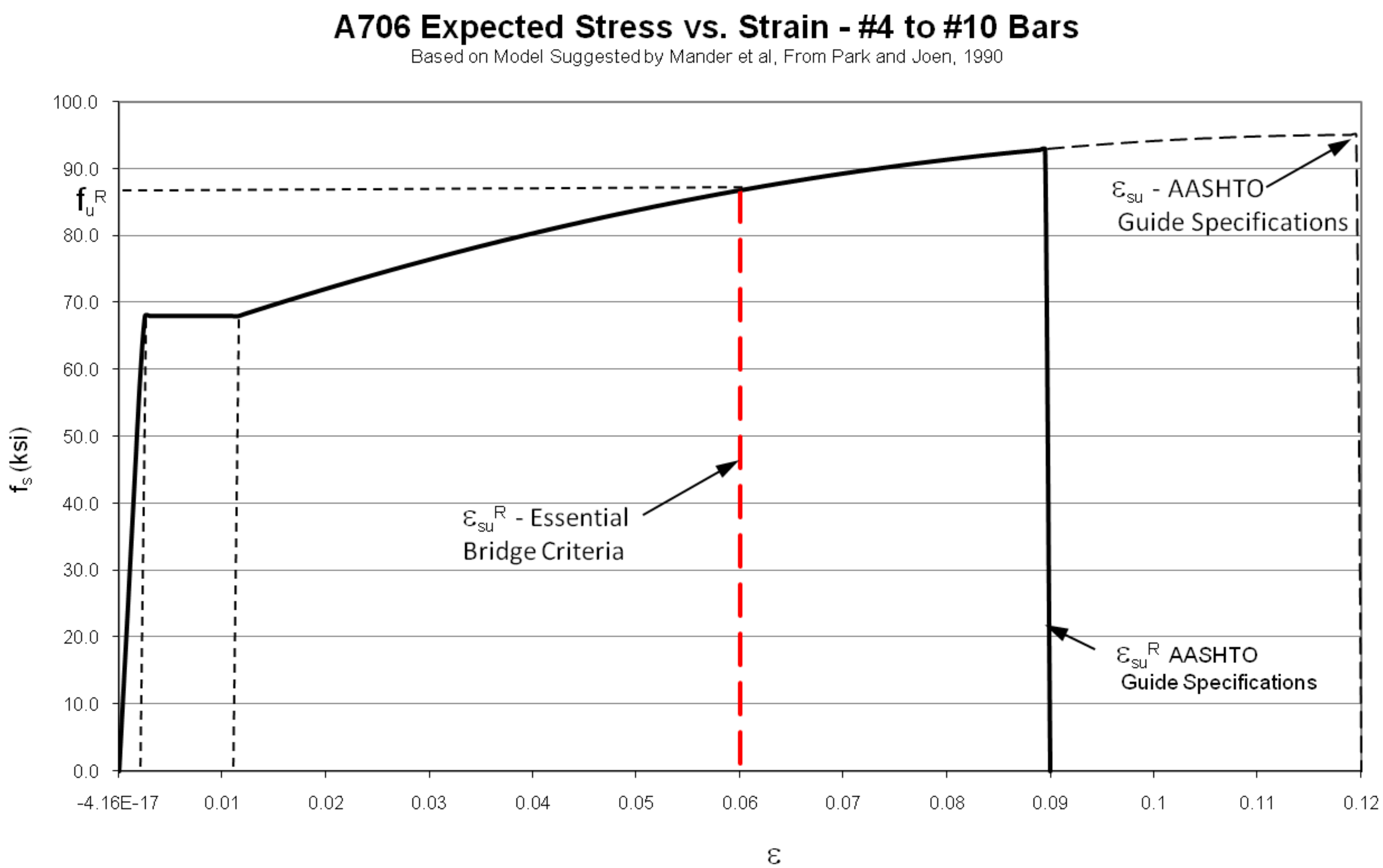
Reduced Strain Limits

Material	Type	AASHTO Guide Specifications Strain Limit	Essential Criteria Reduced Strain Limit
Concrete	Confined	ε_{cu}	$0.67\varepsilon_{cu}$
A706 Steel Reinforcing	#4 to #10	0.090	0.060
	#11 to #18	0.060	0.050

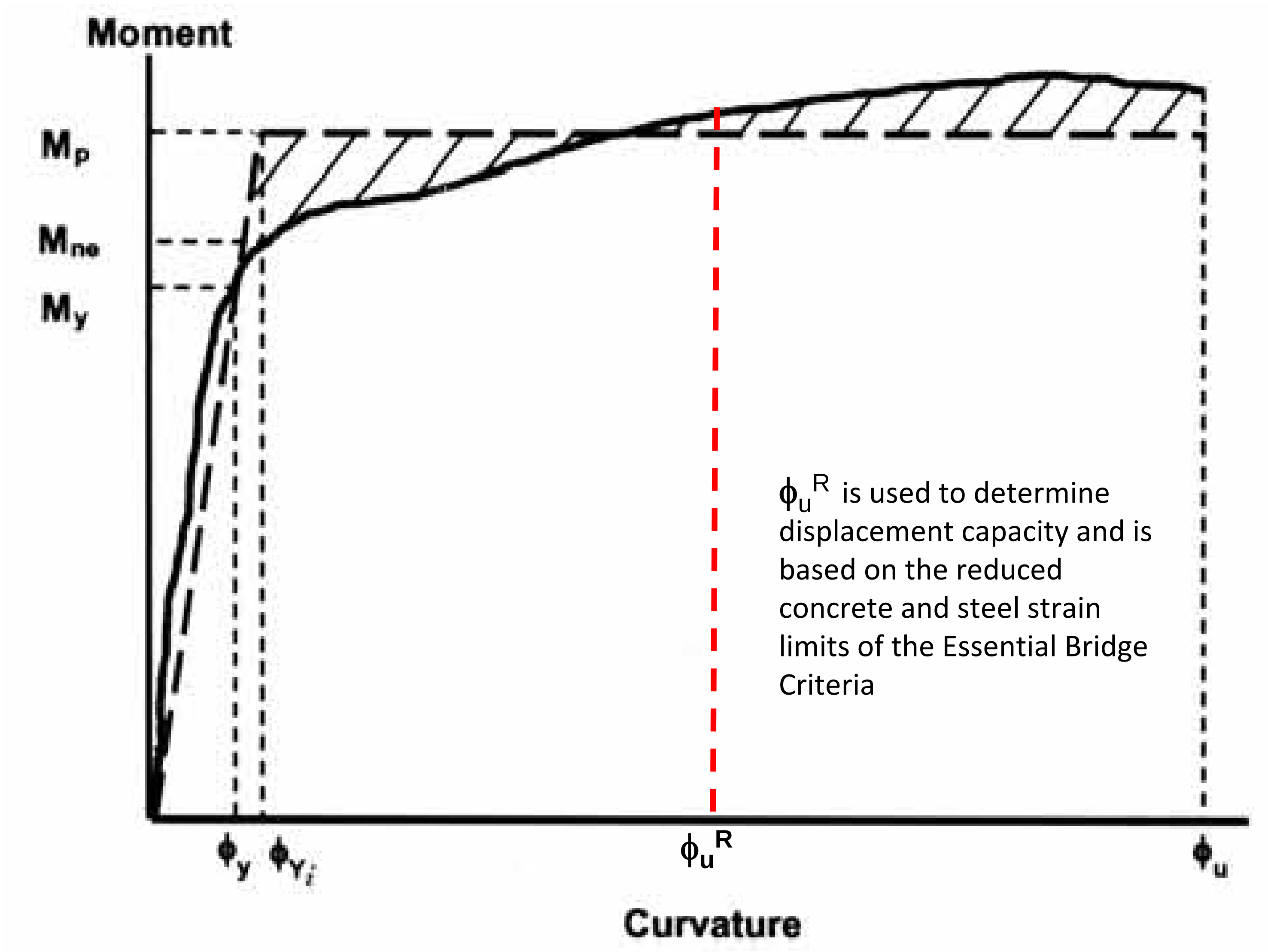
Reduced Concrete Strain Limit



Reduced Steel Strain Limit



Reduced Curvature from Strain Limits



Effects of Vertical Motion

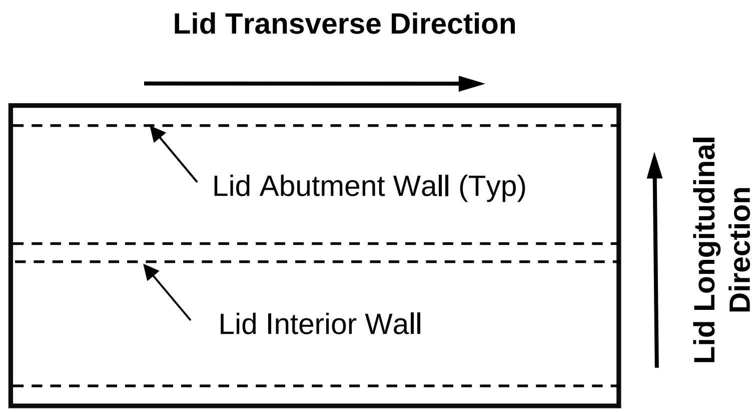
- WSDOT essential bridge criteria requires the use of a site specific vertical response spectrum
- The superstructure shall be designed for 50% of live load concurrent with the EQ Loads
- Directional combinations of the AASHTO guide specifications are required to include 30% of the vertical motion demands.
- An additional directional combination is required that includes100% of the vertical demand and 30% of the horizontal demand in both orthogonal directions.

Lid Features

- Lids provide vehicle and pedestrian crossings, connect communities, provide green/park space, and mitigate noise.
- Landscaped lids require up to 6 feet of soil overburden.

Lid Structural Issues

- Lids are not covered within the scope of the AASHTO guide specifications.
- Lids have large gravity loads from superimposed soil
- Lids have a large seismic mass from superimposed soil
- Lids can be very long and in the transverse direction.
- Long walls can not reduce force demands by hinge formation



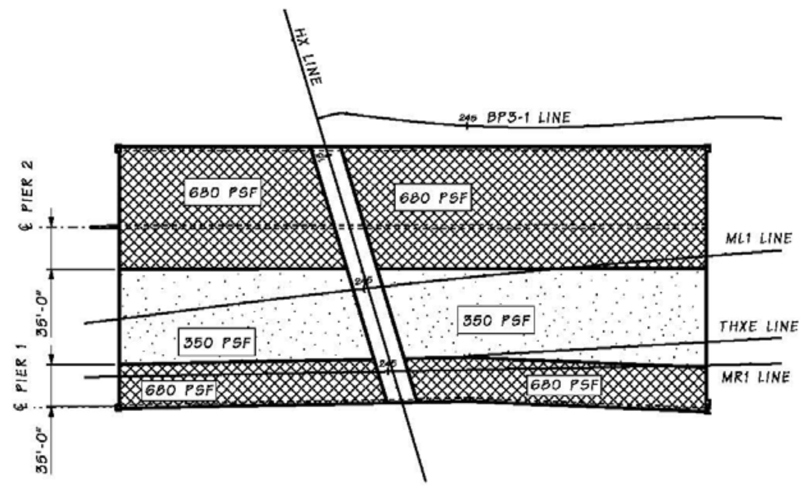
Lid Plan View

Lid Criteria Key Concepts

- The performance objectives are life safety and collapse prevention
- The criteria considers the effects of the superimposed soil mass.
- Permits sliding of lid in the transverse direction.
- Permits a rigid frame abutment ERS
- Permits use of passive abutment resistance
- Requires racking analysis
- Considers Vertical Effects of Ground Motion

Lid General Criteria

- The weight of the soil, landscaping, waterproofing, attachments, utilities and other surface features shall be considered as added mass to the system
- The lid shall be modelled with a vertical center of mass located to accurately represent the inertial forces,
- The vertical center of mass shall not be located lower than the top of the lid deck.
- The center of mass shall be consistent with the load distribution shown on the lid loading diagram.



LOADING DIAGRAM

NOTE:

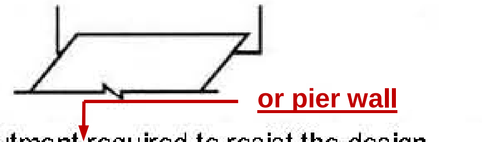
1. LOAD LIMITS SHOWN ARE FOR ALL SUPERIMPOSED LOADS INCLUDING LANDSCAPING AND ARCHITECTURAL ELEMENTS. LOADS ASSUME A SOIL DENSITY OF 110PCF PLUS 20 PSF FOR PLANT MATERIALS. ALL OTHER AREAS ARE DESIGNED FOR AASHTO HL-93 LOADING.
2. THE DESIGN OF THE STRUCTURE INCLUDES AN ADDITIONAL 100 PSF FOR PEDESTRIAN LIVE LOAD ON LANDSCAPED AREAS.

Lid Transverse Criteria

- Modifies ERS # 5 of the AASHTO guide specifications to include pier walls that resist the design earthquake elastically.
- Permits an ERE for lid walls with spread footings that satisfy the overturning criteria of the AASHTO guide specifications, but are allowed to slide parallel to the strong axis of the wall.
- Adds a requirement to determine the magnitude of sliding and proportion structure for differential sliding between piers.

5
MODIFY

Transverse or Longitudinal Response



- Abutment required to resist the design earthquake elastically
- Longitudinal passive soil pressure shall be less than 0.70 of the value obtained using the procedure given in Article 5.2.3

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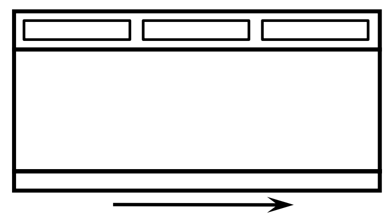
NEW



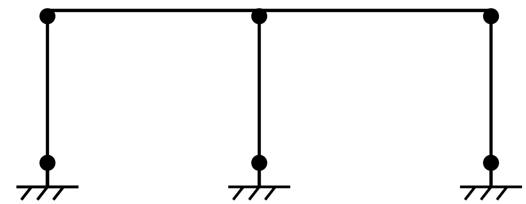
- **Sliding of pier wall allowed in the strong direction of the wall.**
- **Design structure to remain elastic under forces induced by sliding and differential sliding of piers.**

Lid Longitudinal Criteria

- Permits a rigid frame abutment type ERS.
- Permits the following EREs:
  - plastic hinges below cap beams for lid walls in the weak direction (Modifies ERE #1)
  - Plastic hinges at the base of lid walls in the weak direction
  - Pre-approval for abutment resistance to 50% of passive soil strength

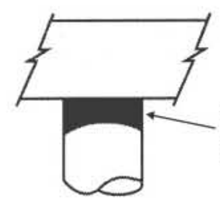
Longitudinal Response

7
NEW



- Plastic hinges in inspectable locations of columns and in the weak direction of pier and abutment walls.
- Passive Abutment resistance using 50 percent of the passive soil strength permissible

Permissible Earthquake Resisting System (ERS) # 7 – permitted for lid design



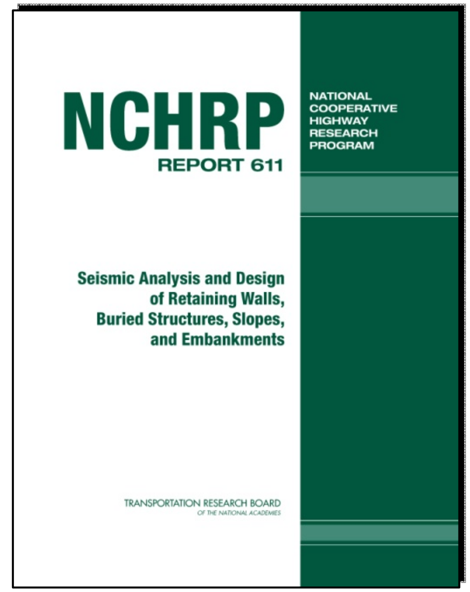
Plastic hinges below cap beams including pile bents **and walls (in the weak direction)**

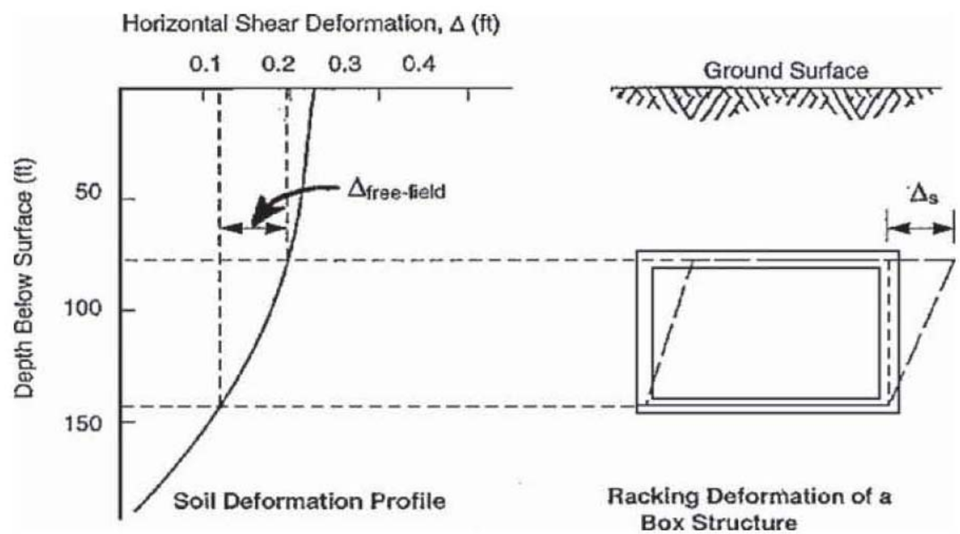
1
MODIFY

Permissible Earthquake Resisting Element (ERE) # 1 – modified for lid design

Lid Longitudinal Criteria

- Requires a racking analysis in accordance with NCHRP 611 if any of the permitted longitudinal ERSs of EREs are used
- The racking analysis shall use the results of the nonlinear static procedure (NSP) for displacement capacity, in accordance with the AASHTO Guide Specifications and WSDOT Design Memoranda.





Lid Vertical Criteria

- Considers vertical ground motion in accordance with section 4.7.2 of the AASHTO Guide Specifications.
- As a minimum, the vertical analysis procedure shall use a 2-D longitudinal model and a site-specific vertical response spectrum to determine superstructure demands from vertical ground motions.

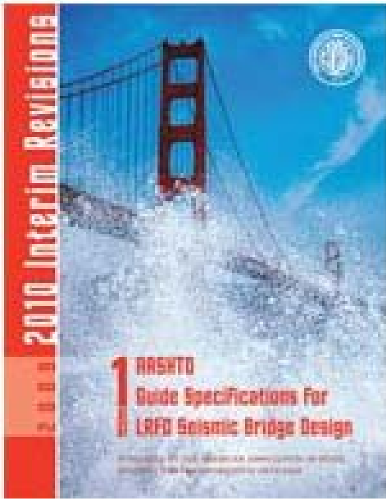
Lid Vertical Criteria (Continued)

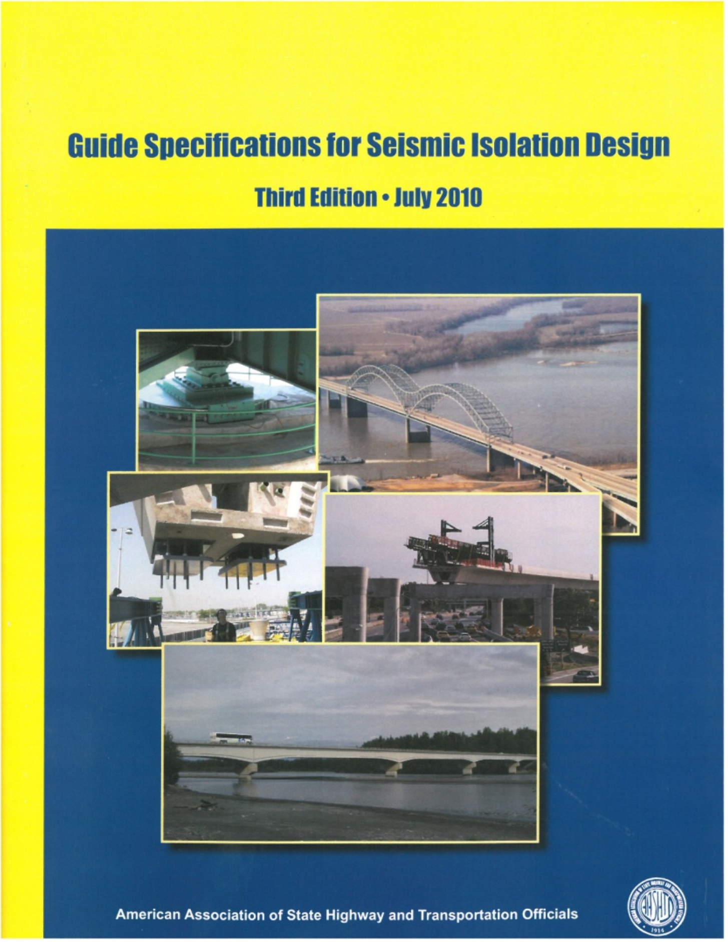
- Two vertical ground motion response load combinations shall be considered.
  - V1 1.0 DC + 1.0 DW + 1.0 EV + 1.0 EH ± 1.0 EQV
  - V2 1.0 DC + 1.0 DW + 1. 0EV ± 1.0 EQH ± 1.0 EQV
- In load combination V1 the superstructure is required to remain elastic
- In load combination V2 moment redistribution is permissible in the superstructure.

Seismic Isolation Codes and Specifications

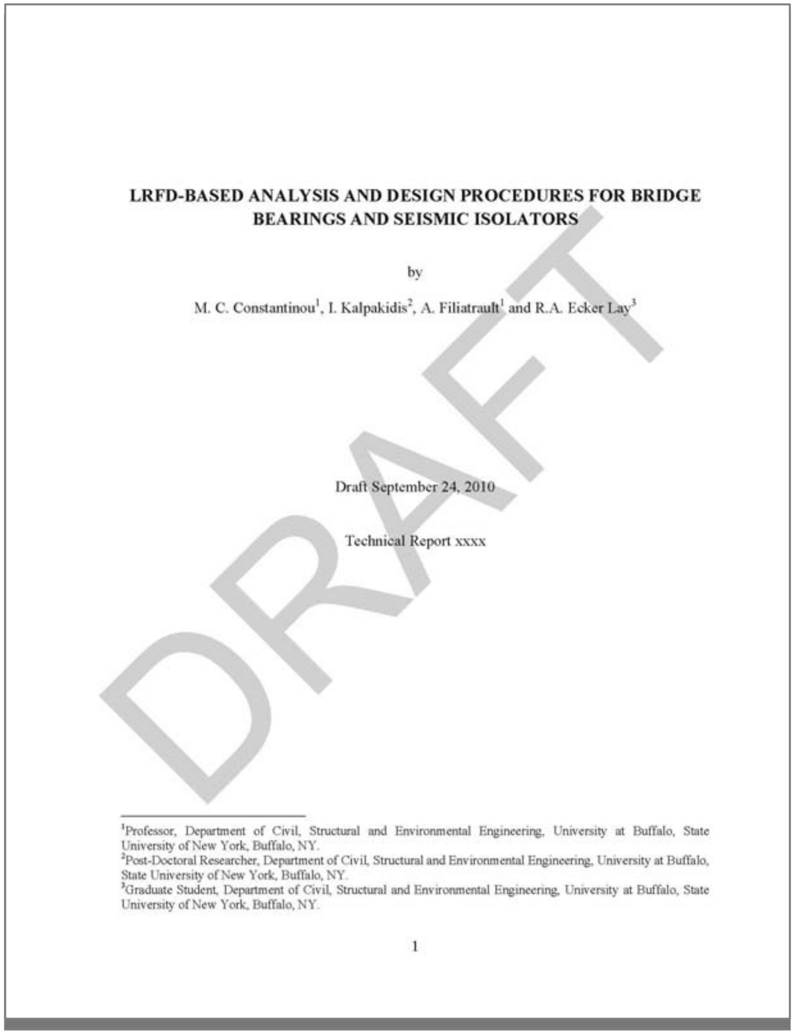
- *Guide Specifications for Seismic Isolation Design, Third Edition (July 2010), published by the* American Association of State Highway and Transportation Officials.

- *AASHTO Guide Specifications for LRFD Seismic Bridge Design, First Edition (2009) with* Interim Revisions through 2010, published by the American Association of State Highway and Transportation Officials.





Seismic Isolation References



LRFD-BASED ANALYSIS AND DESIGN PROCEDURES FOR BRIDGE BEARINGS AND SEISMIC ISOLATORS

by

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Draft September 24, 2010

Technical Report xxxx

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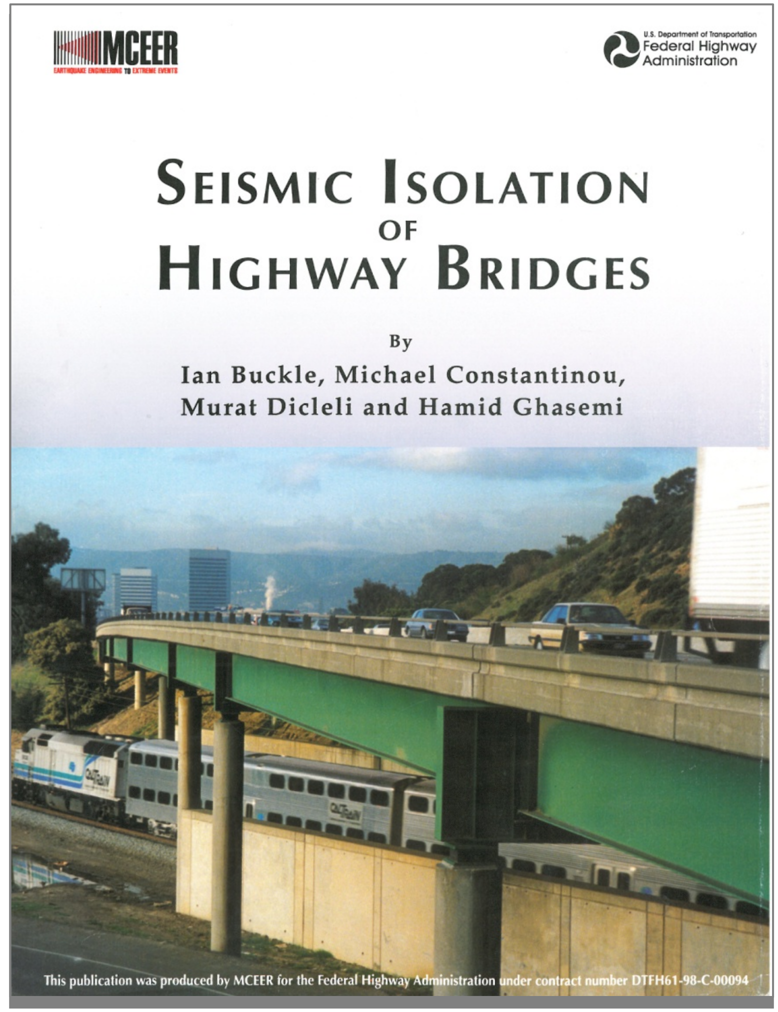


Seismic Isolation Criteria – Key Concepts

- Performance is essentially elastic under the Design Earthquake
- Live Load Considered Simultaneously with Seismic Load (γ_{LL} = 0.5).
- Added Factor of Safety to prevent inelastic behavior in Foundation elements (1.2 times elastic Seismic Force
- Ductile Detailing provided in Column Plastic Hinge Zones (if Mu> 2/3 Mp, based on design properties)
- Added Factor of Safety for Shear in Columns (ϕ=0.67 for column shear capacity)

In Closing

- As part of the SR 520 Bridge Replacement Program WSDOT has:
- Developed an essential bridge criteria and seismic isolation criteria that will improve the probability that the SR 520 Mainline bridges can remain in service after the design earthquake event.
- Incorporated a lid seismic criteria into design-build contract requirements that will help achieve the objective of life safety during the design earthquake event.

Questions ?

Web Site:

www. wsdot.wa.gov/projects/SR520Bridge

E-mail:

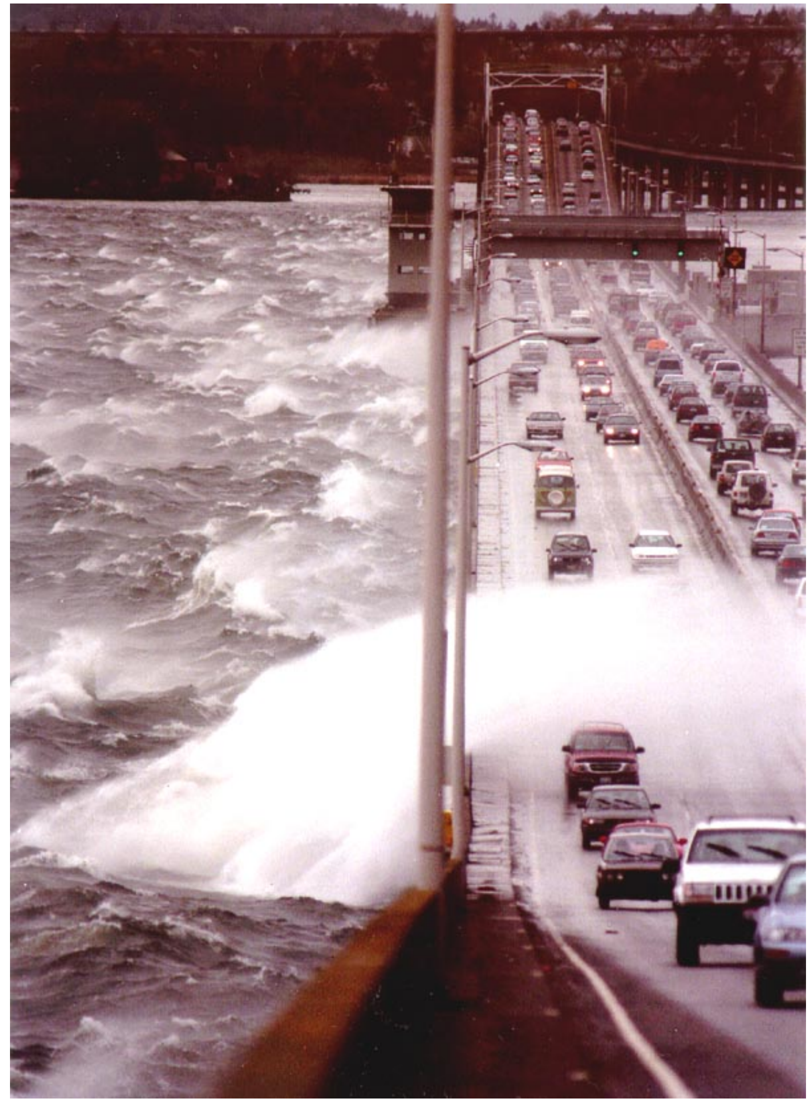
nutsong@consultant.wsdot.wa.gov

Existing Bridge Data

- Opened August 8th, 1963
- 2.3 mile long crossing
- Originally designed for 57 mph wind
- Retrofitted in 1998 to withstand 20 year storm - 77 mph wind
- Designed for 65,000 trips per day
- 60 feet wide with 4 lanes of traffic

Program Goals

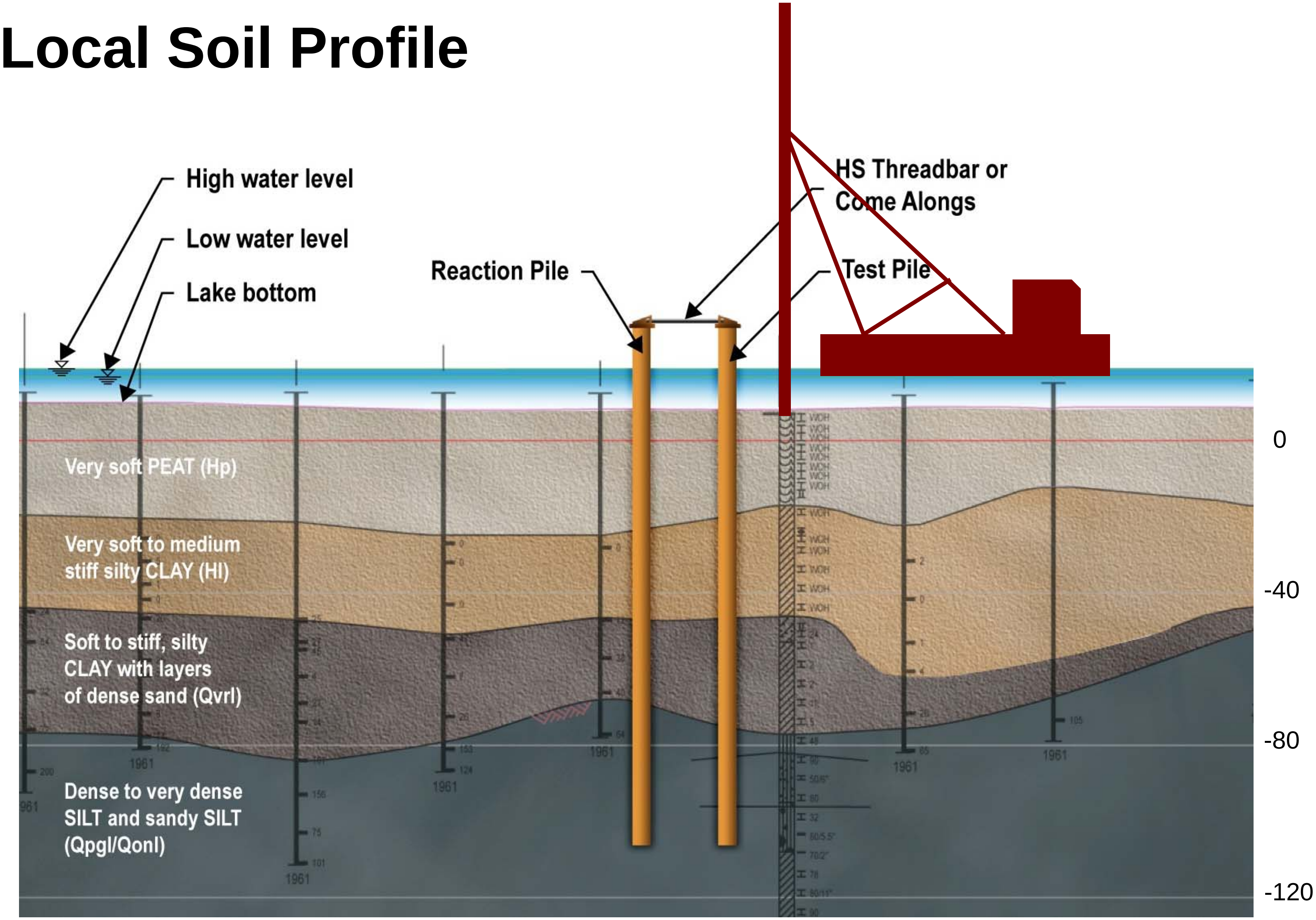
- Improve Safety and Reliability
- Increase mobility for people and goods
- Avoid, minimize, and/or mitigate the project effects on the environment and neighborhoods



Project Setting and Environment

- Vital link across Lake Washington
- Wetlands
- Parklands
- Urban neighborhoods
- University property
- Navigable waterways
- Recreational waters
- Endangered species habitat
- Tribal fishing waters
- Historical and Cultural resources

Local Soil Profile

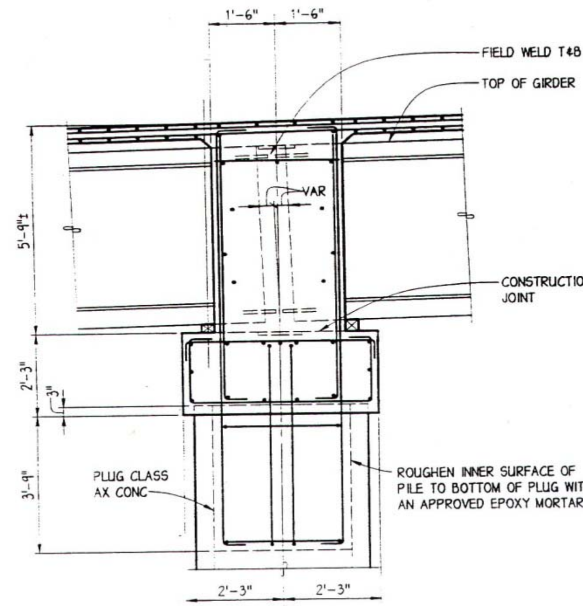


Existing Bridge Deficiencies

- Vulnerable to catastrophic failure during large windstorms
- Vulnerable to collapse from earthquakes
- Vulnerable to collapse from vessel impact
- Does not have shoulders
- Daily traffic volumes exceed capacity
- No HOV, bicycle, or pedestrian features
- Discharges untreated storm water run-off into Lake Washington

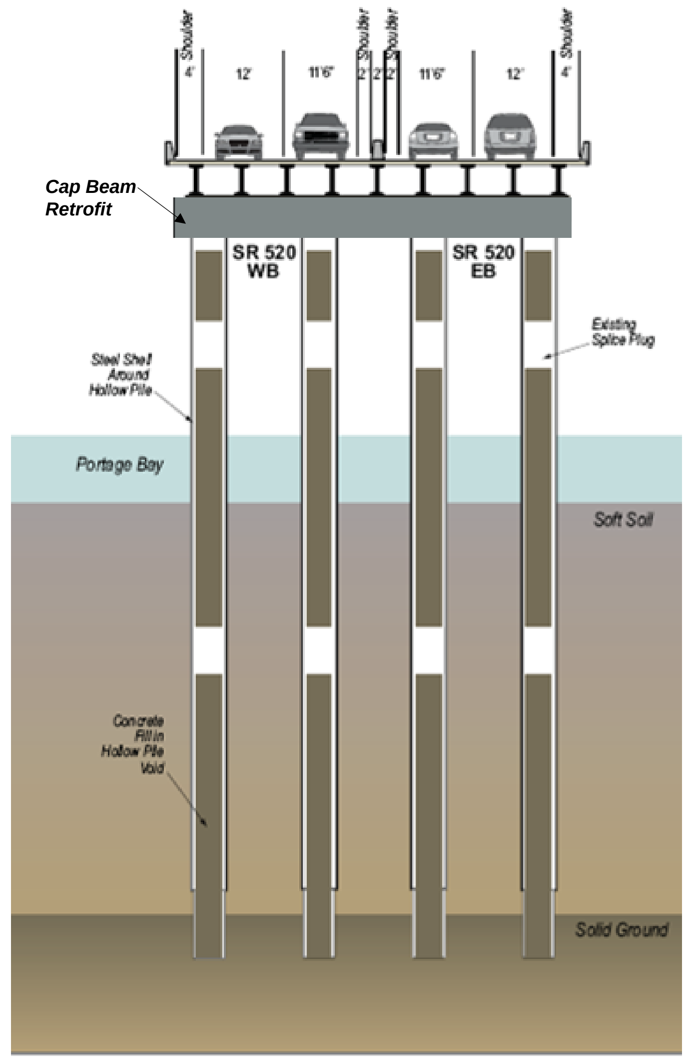
Existing Seismic Deficiencies

- Insufficient ductility in hollow prestressed concrete piles due to unconfined concrete at the inside face of piles.
- Insufficient confinement at outside face of piles.
- Plug connection from piles to cross beam can not develop plastic strength of piles
- Insufficient positive moment reinforcement in superstructure over crossbeams
- Joints and Anchor Cables Vulnerable to damage from Seiche
- C/D ratios as low as 0.3 for the design earthquake



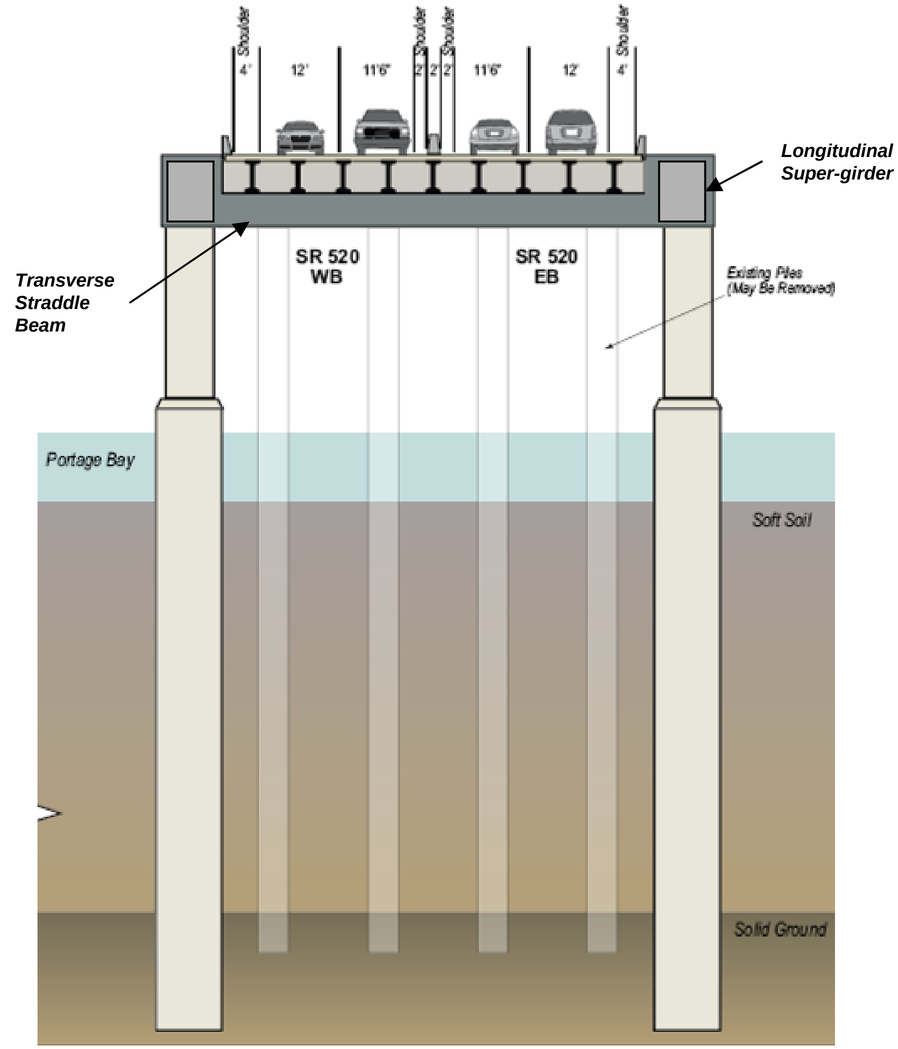
Retrofit Concept – Scheme 1

- Install Steel Column Casing
- Fill Hollow Piles with concrete or grout
- Strengthen Plug Connection
- Strengthen Cap Beams
- Strengthen Superstructure



Retrofit Concept – Scheme 2

- Straddle beam supports the existing superstructure and provides a cross beam for the transverse frame.
- Large drilled shafts connect to the outriggered portion of the straddle beam eliminating the need for the existing hollow piles
- Super-girders create a longitudinal frame, and reduce demands to the existing superstructure



Retrofit Conclusions

- The construction cost would be nearly the same as a replacement bridge.
- Construction access would be very difficult. Retrofit measures would be required to be performed underwater or in cofferdams
- Untested construction methods would be required
- Would not improve vehicle capacity, roadway safety, or drainage issues.
- Bridges would not be aesthetically improved and may have increased adverse visual impacts.
- Would not reduce the cost of maintaining the aging structure

Seismic Hazard Analysis

- Seismic hazard based on 7% probability of exceedance in 75 years (1000 year return period)
- Phase 1 Hazard Analysis
  - Based on a 2007 USGS 3D PSHA for Seattle which included basin and directivity effects.
- Phase 2 Hazard Analysis
  - Site Specific PSHA
  - Used next generation attenuation (NGA) relations, which provided a refined estimate of hazard.

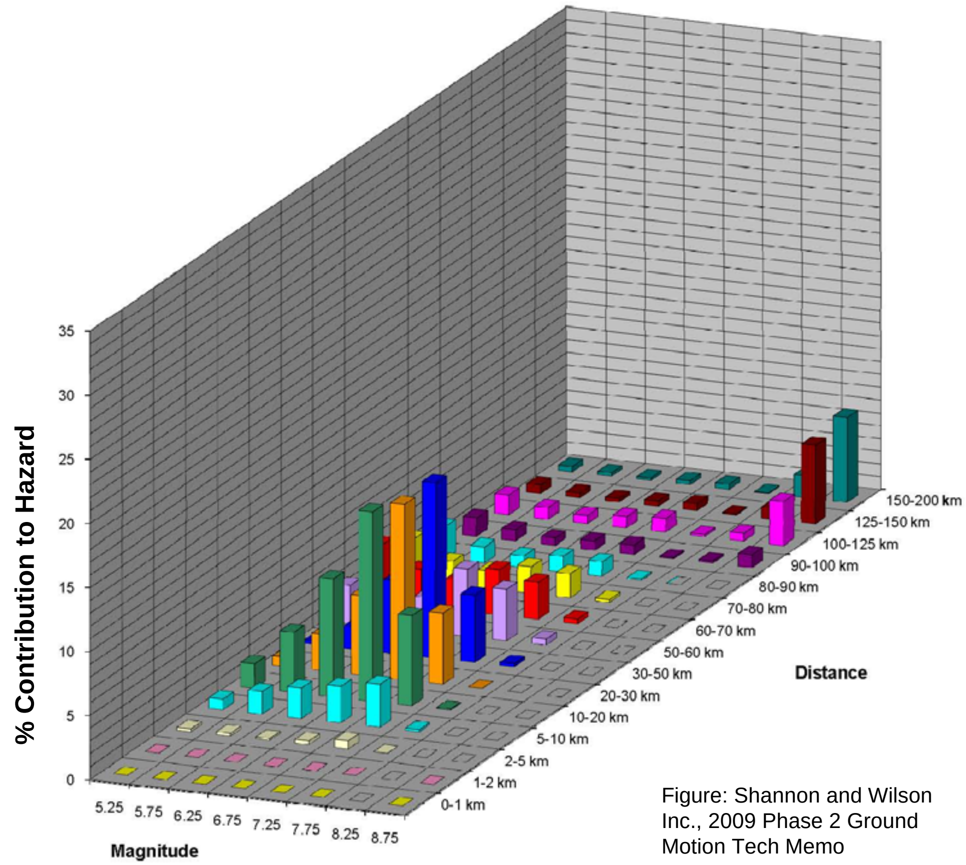
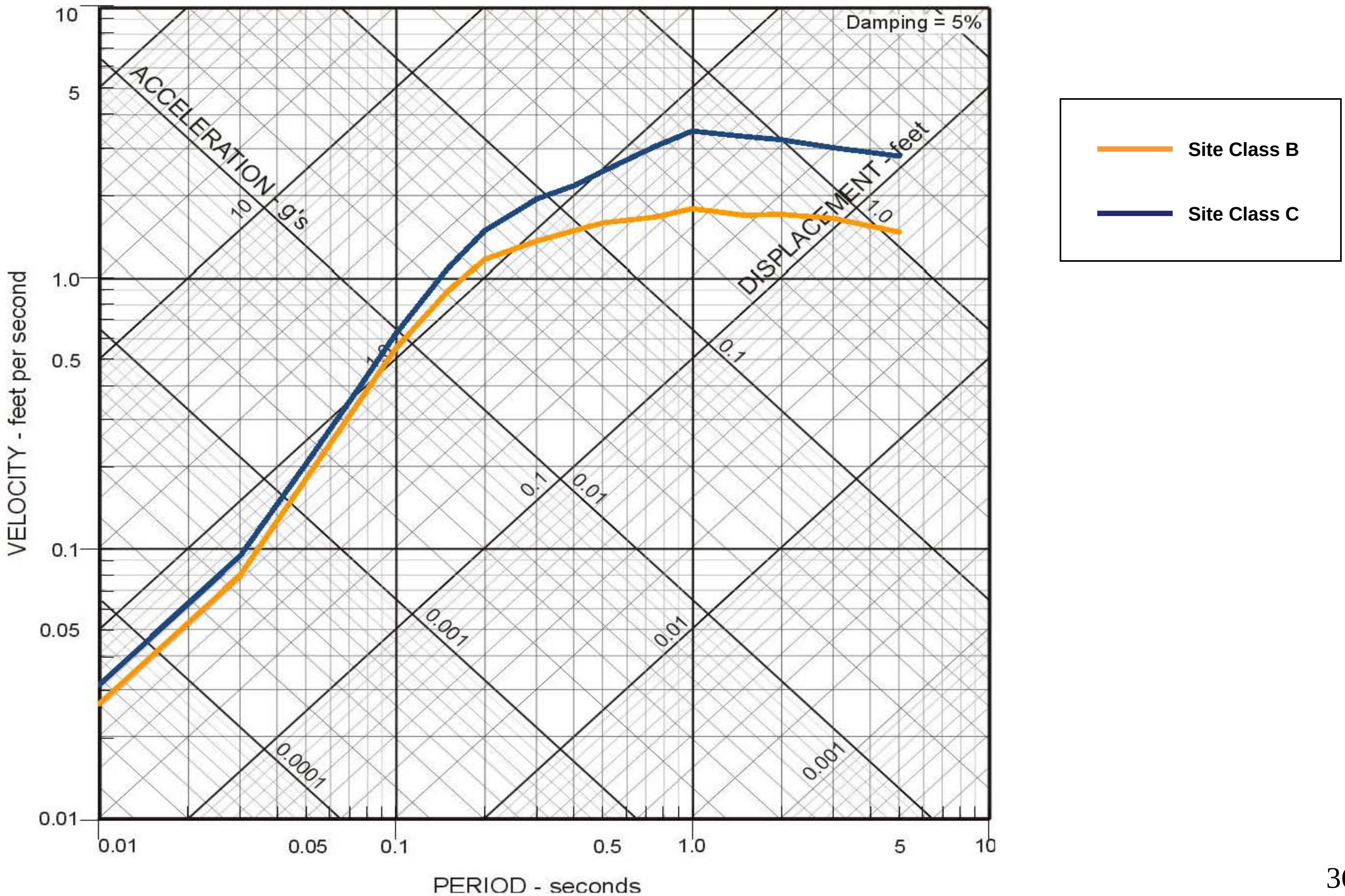


Figure: Shannon and Wilson Inc., 2009 Phase 2 Ground Motion Tech Memo

Design Response Spectra



Design Response Spectra