Western Bridge Engineers' Seminar

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SESSION 4A

PHOENIX, ARIZONA

Implementation of the AASHTO LRFD Seismic Bridge Design Guide Specifications: Case Studies

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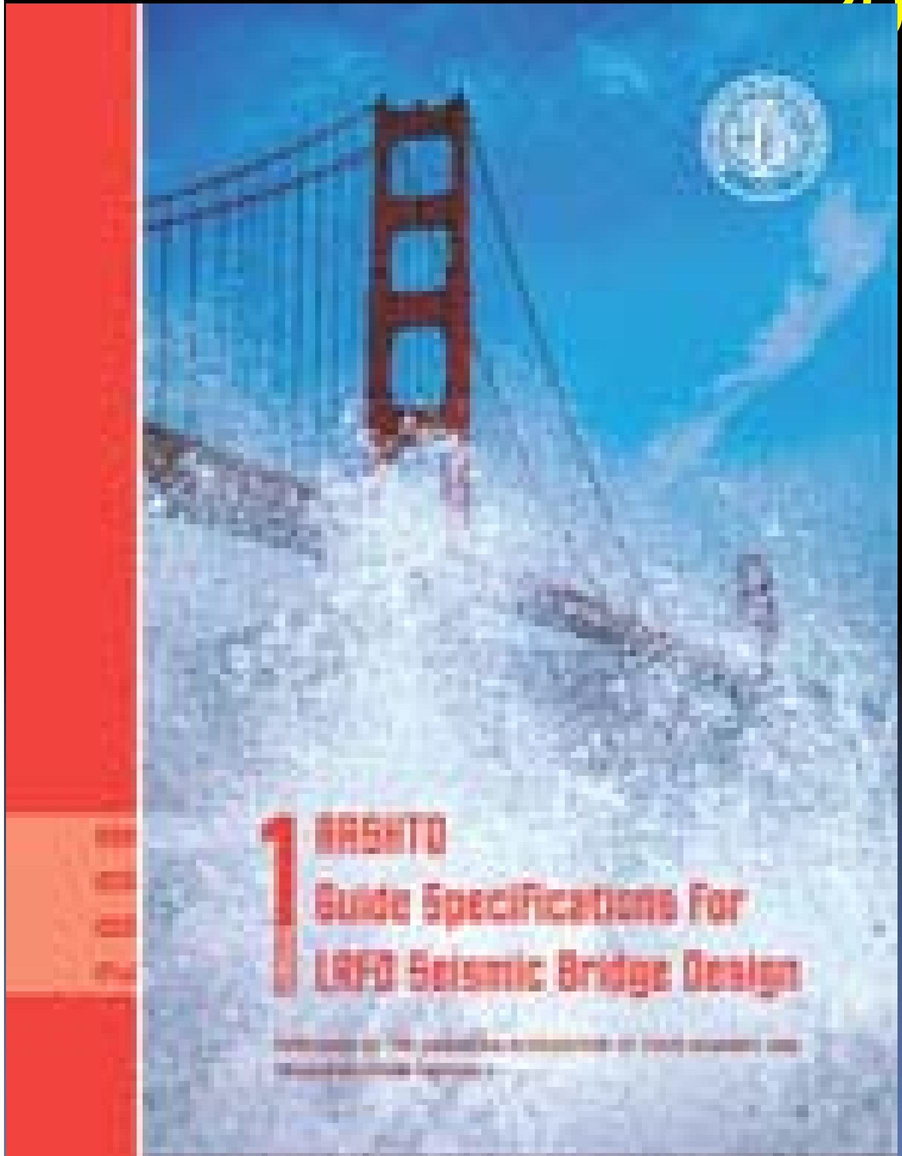
Presentation Outline:

Case Studies:

- Elastic Design
- Column Reinforcement
- Column-to-shaft Connection
- Consideration for LL
- Multi Hazard
- Group Reduction Factor
- Isolation Bearings

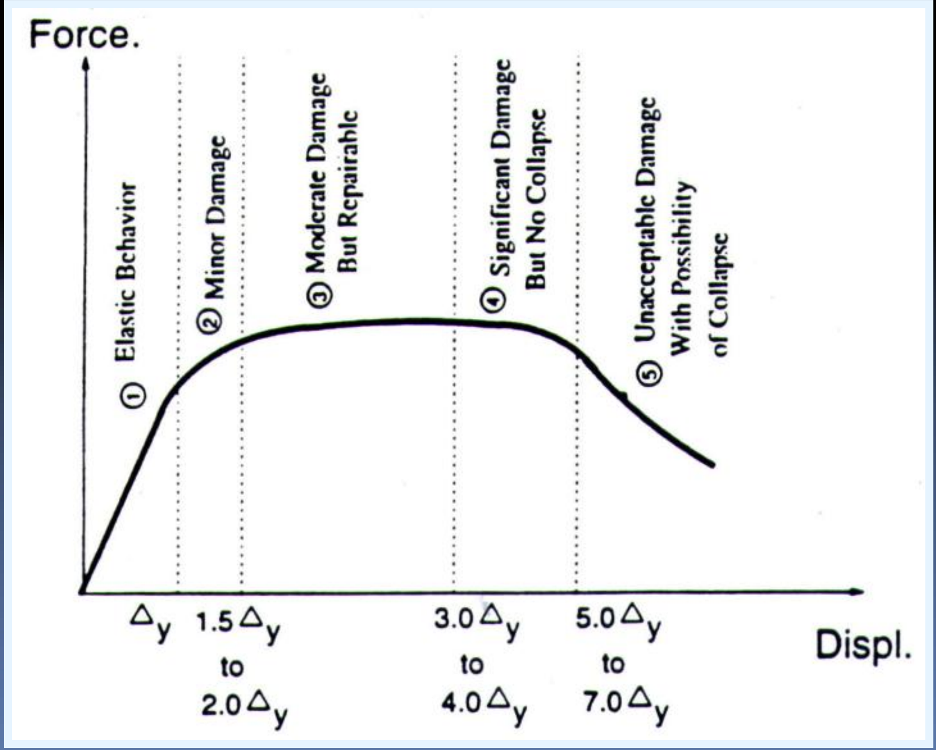
Bridge Seismic Design

LRFD Seismic Guide Specs (SGS) Since 2008

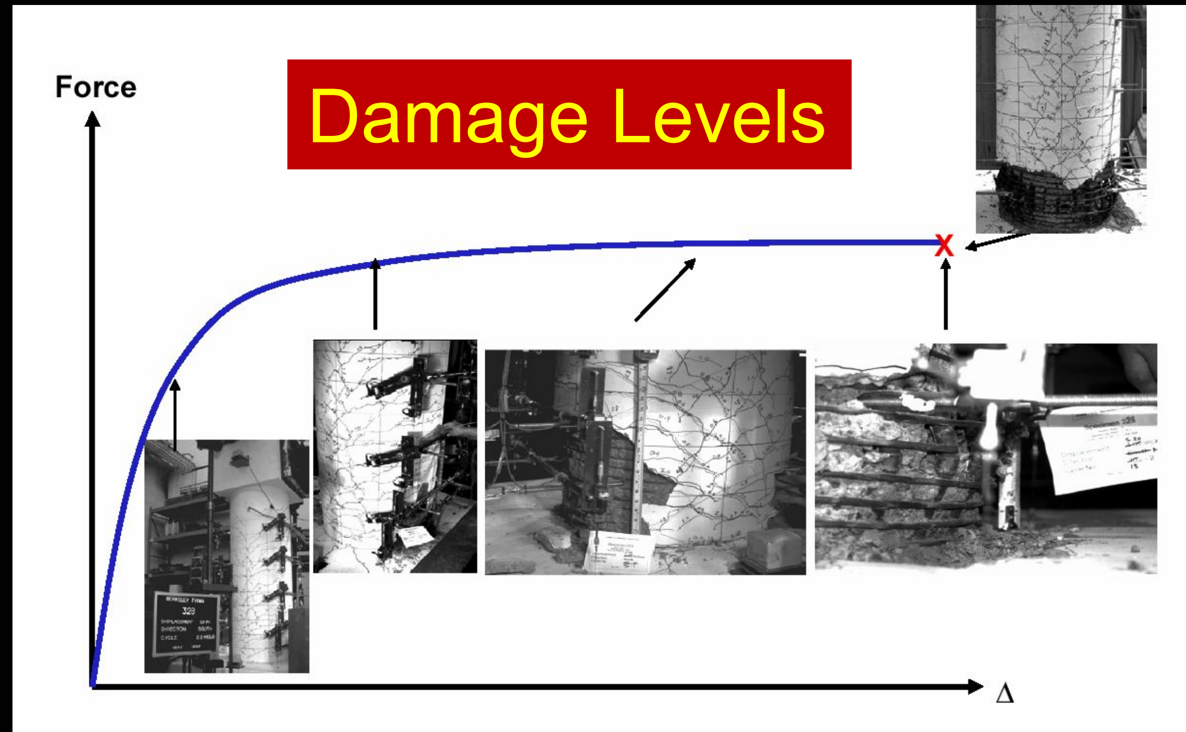


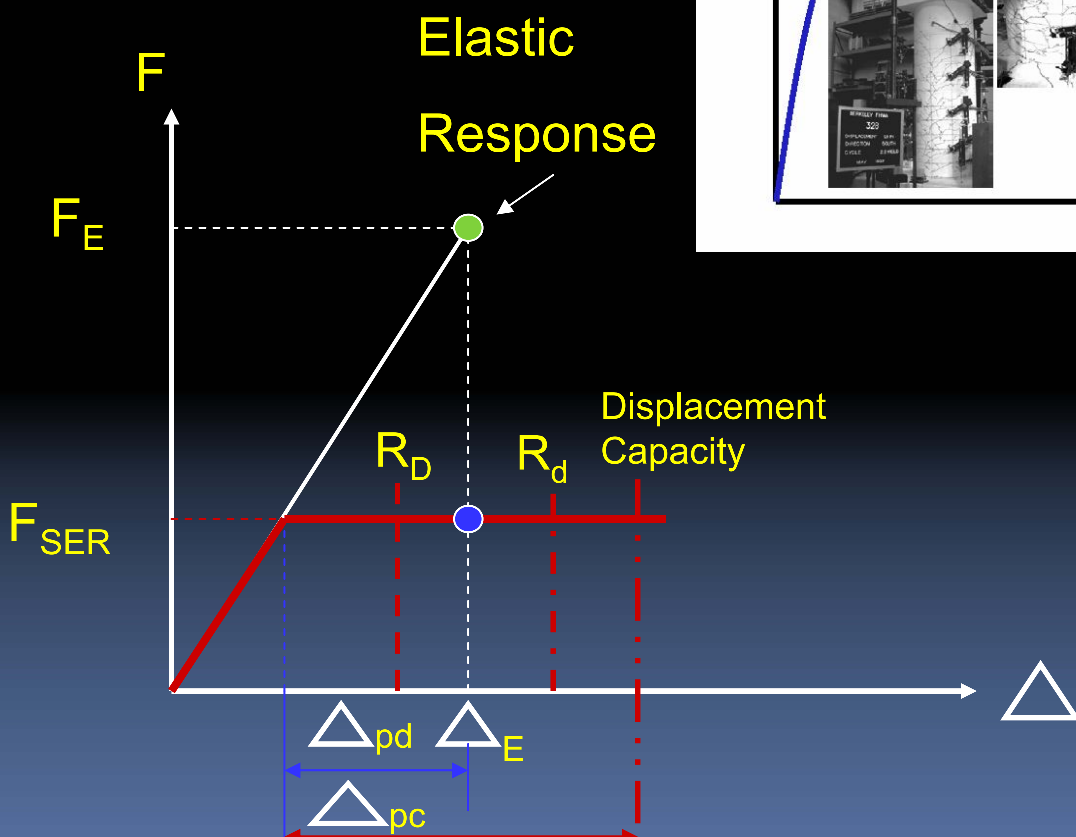
Typical WSDOT Design Strategy:

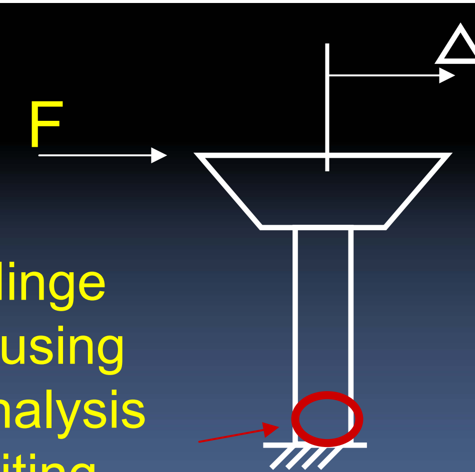
Type 1: Ductile Substructure with Essentially Elastic Superstructure



AASSHTO Guide Specs for LRFD Bridge Seismic Design (SGS)



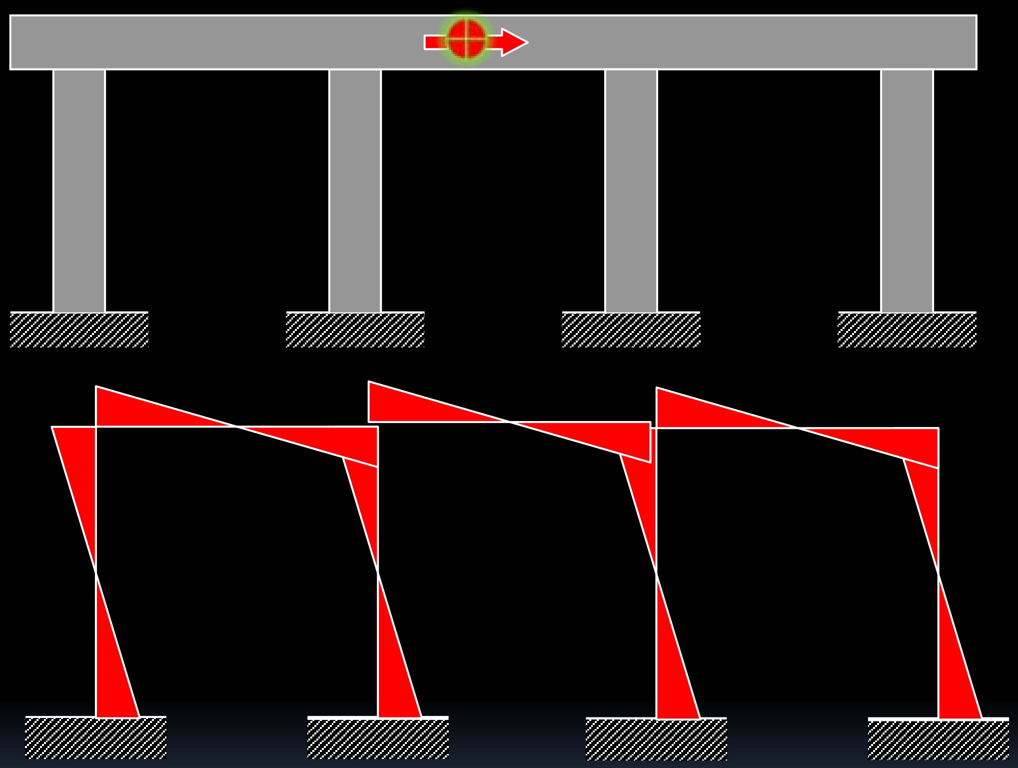




Plastic Hinge Capacity using Section Analysis with Limiting Steel and Concrete Strains

Performance Based Design

Bridge Substructure Seismic Design



Typical WSDOT Precast prestressed girder bridge with dropped bent cap

Connections need to be:

- Constructible
- Long term Performance and
- Adequate For Seismic

SGS 4.11: Capacity Design of Bridges Using Overstrength Concepts

- For reinforced concrete members:

$M_{po} = \lambda_{mo} M_p$

where:

M_p = *plastic moment capacity of column*

λ_{mo} = *overstrength factor taken as 1.2 or 1.4*

A706: λ_{mo} = 1.2

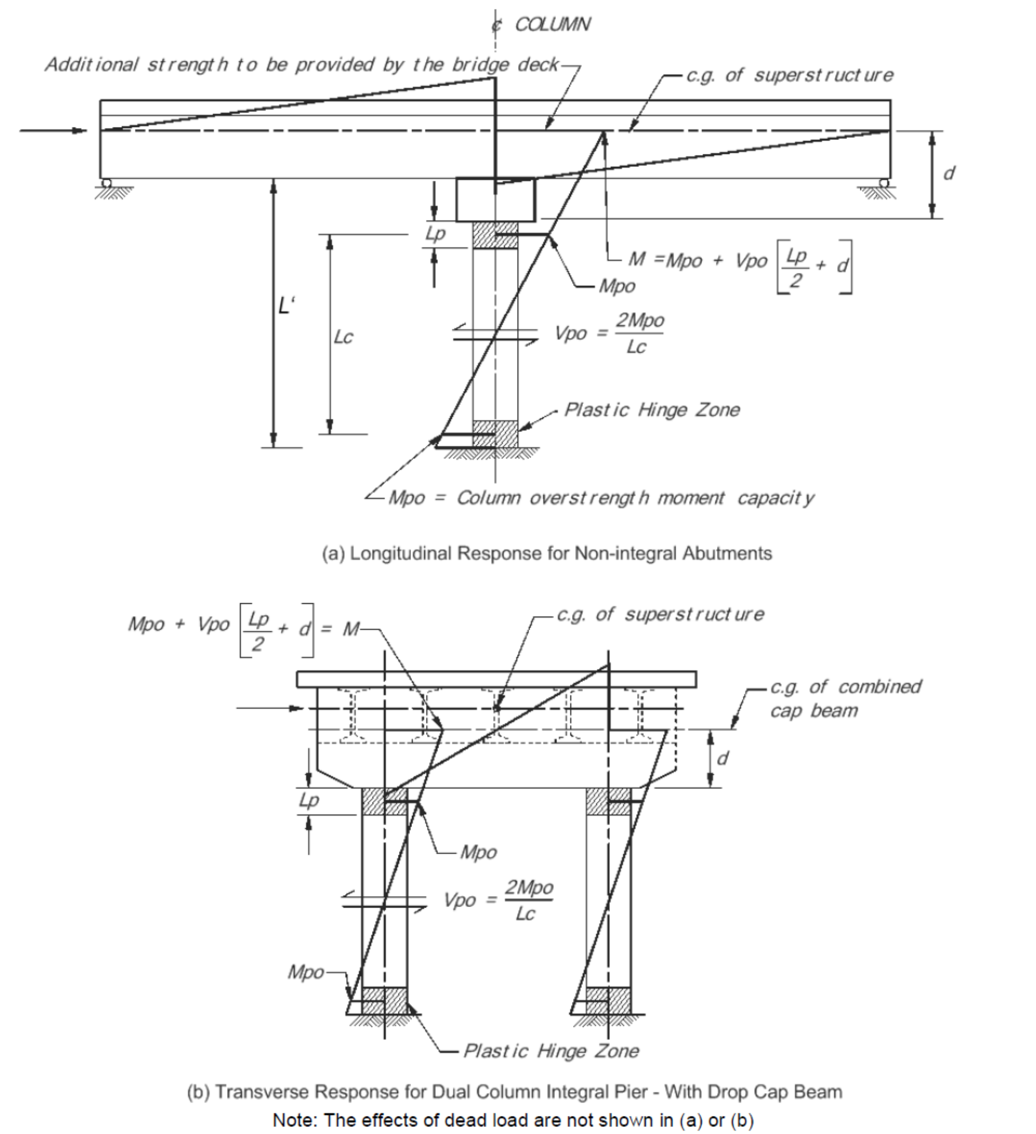


Figure 4.11.2-2—Capacity Design Using Overstrength Concepts – ~~NonI~~Integral Bent Cap

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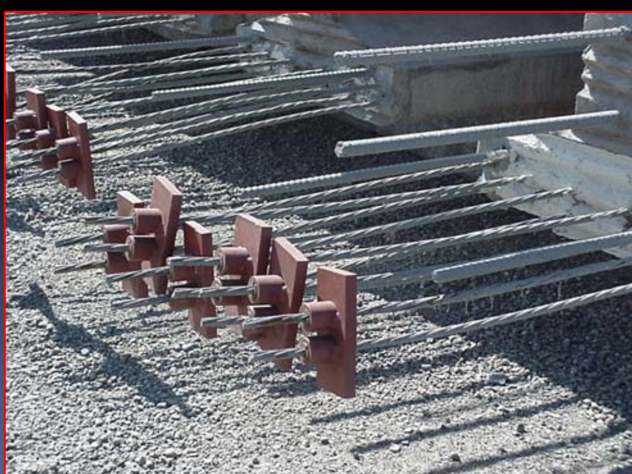
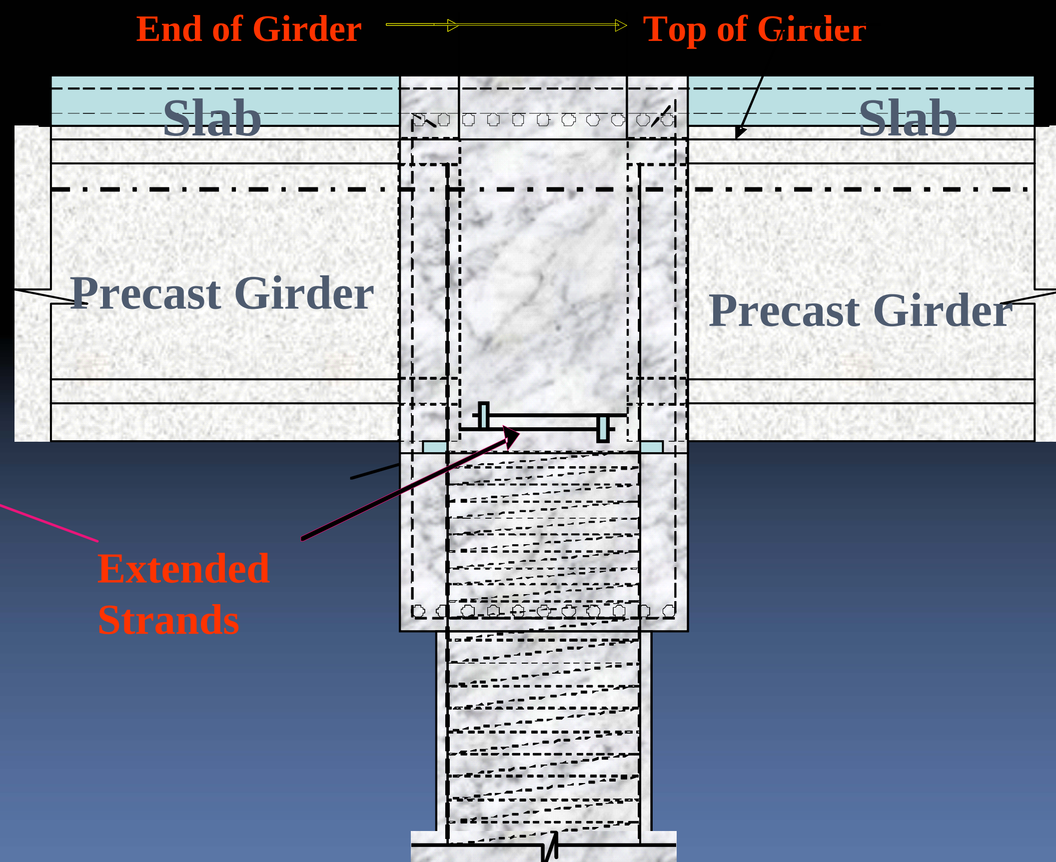
SGS - C8.8.4: Column Reinforcement

For The Case Of Precast Girder Structures With Two-stage Integral Cap Beams, The Column Longitudinal Reinforcement Could Be Extended To The Top Of The Lower Stage Of The Cap Beam.





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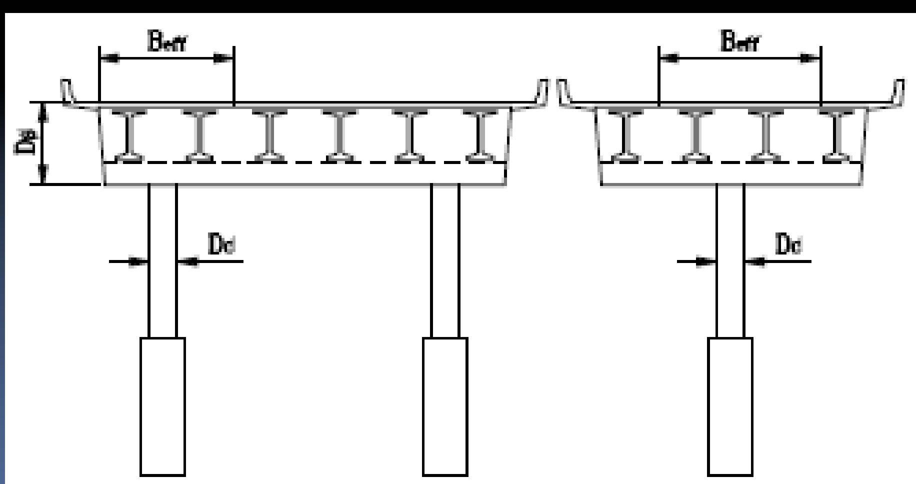
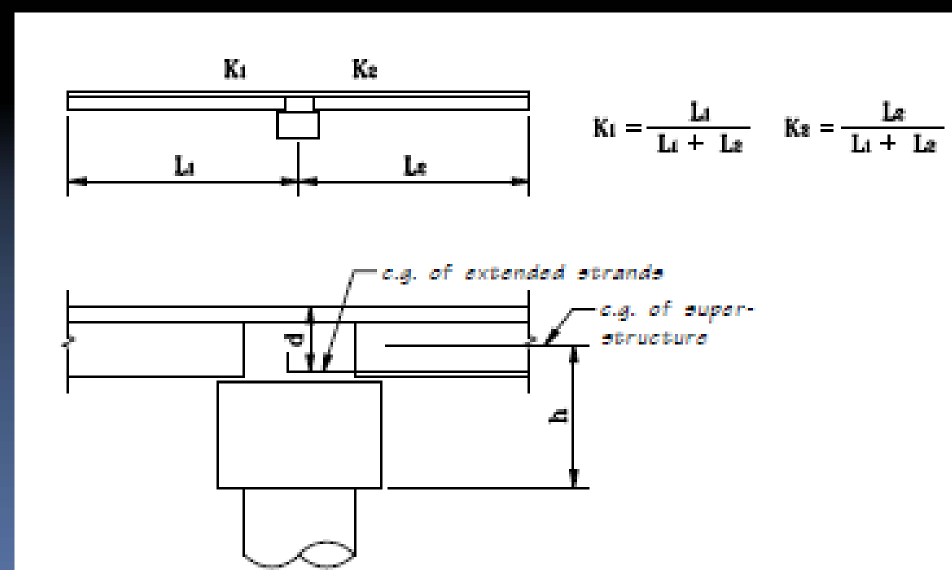
SGS 8.10: Effective Width

For Precast Prestressed Girder Bridges, Two-thirds Of The Longitudinal Seismic Moment May Be Resisted By Girders Within The Effective Width, *And The Remaining One-third By The Girders* Outside The Effective Width.



Effective Superstructure Width for Extended Strand Design



Extended Strand Design

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SGS 8.8.10: Non-Contact Lap Splice

Column longitudinal reinforcement should be extended into oversized enlarged shafts in a staggered manner with the minimum embedment lengths of:

$D_{c,max} + l_d$ *and* $D_{c,max} + 2\, l_d$

Other methods of developing longitudinal column reinforcement in the shaft may be used if confirmed by experimental test data and approved by Owner.

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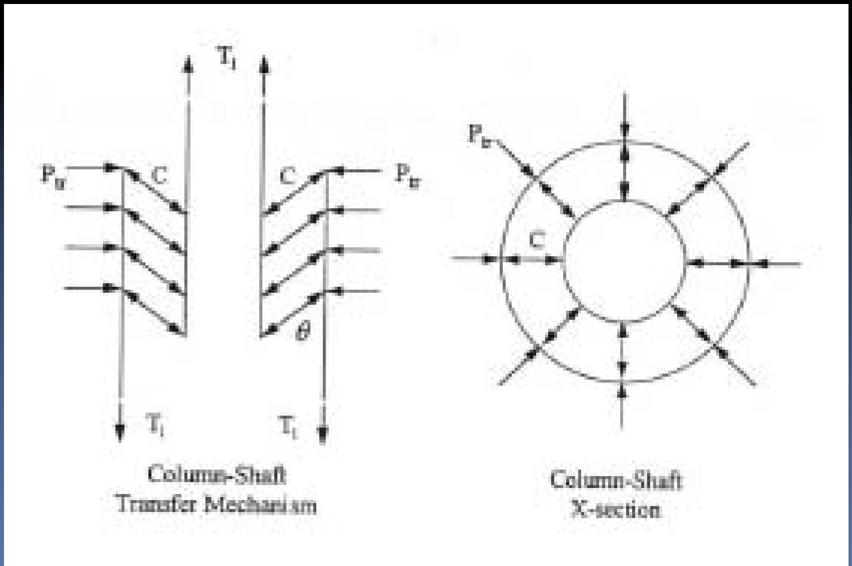
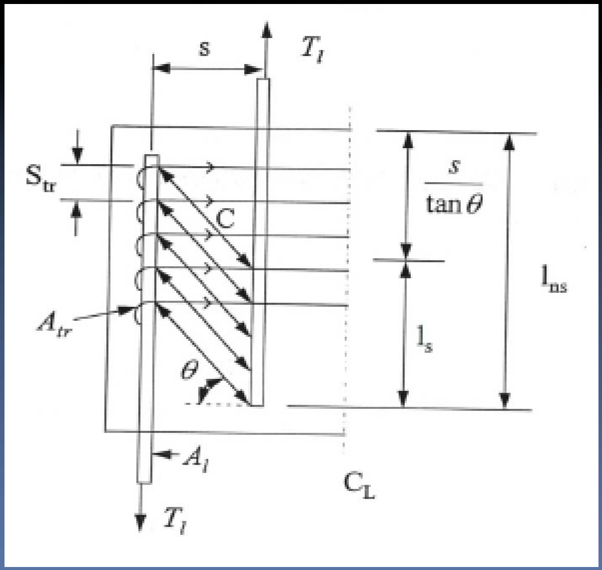
Column – Shaft Connection – UW

Column – Shaft Connection – WSU





$$S_{tr} = \frac{2\pi A_{sp} f_{ytr} l_s}{k A_l f_{ul}}$$

AASHTO
LRFD
2009

AWV Bridge Replacement

- Difficulty designing short circular columns for expected overstrength shear forces.

Columns (6'-6" diameter) are oversized due to their proximity to a railroad. The structure is in SDC D due to liquefiable soils.

LRFD 5.7.4.2—Limits for Reinforcement

The minimum area of longitudinal reinforcement for compression components shall be such that:

$$\frac{A_s f_y}{A_g f'_c} + \frac{A_{ps} f_{pu}}{A_g f'_c} \geq 0.135$$

f'c	As/Ag >0.135 f'c/fy
4	0.900%
6	1.350%
8	1.800%
10	2.250%

SGS 8.8.2—Minimum Longitudinal Reinforcement

The min. area of reinf shall not be less than:

- For columns in SDCs B and C: $A_\ell \geq 0.007A_g$
- For columns in SDC D: $A_\ell \geq 0.010A_g$

ACI 10.9 — Limits for reinf. of comp. members

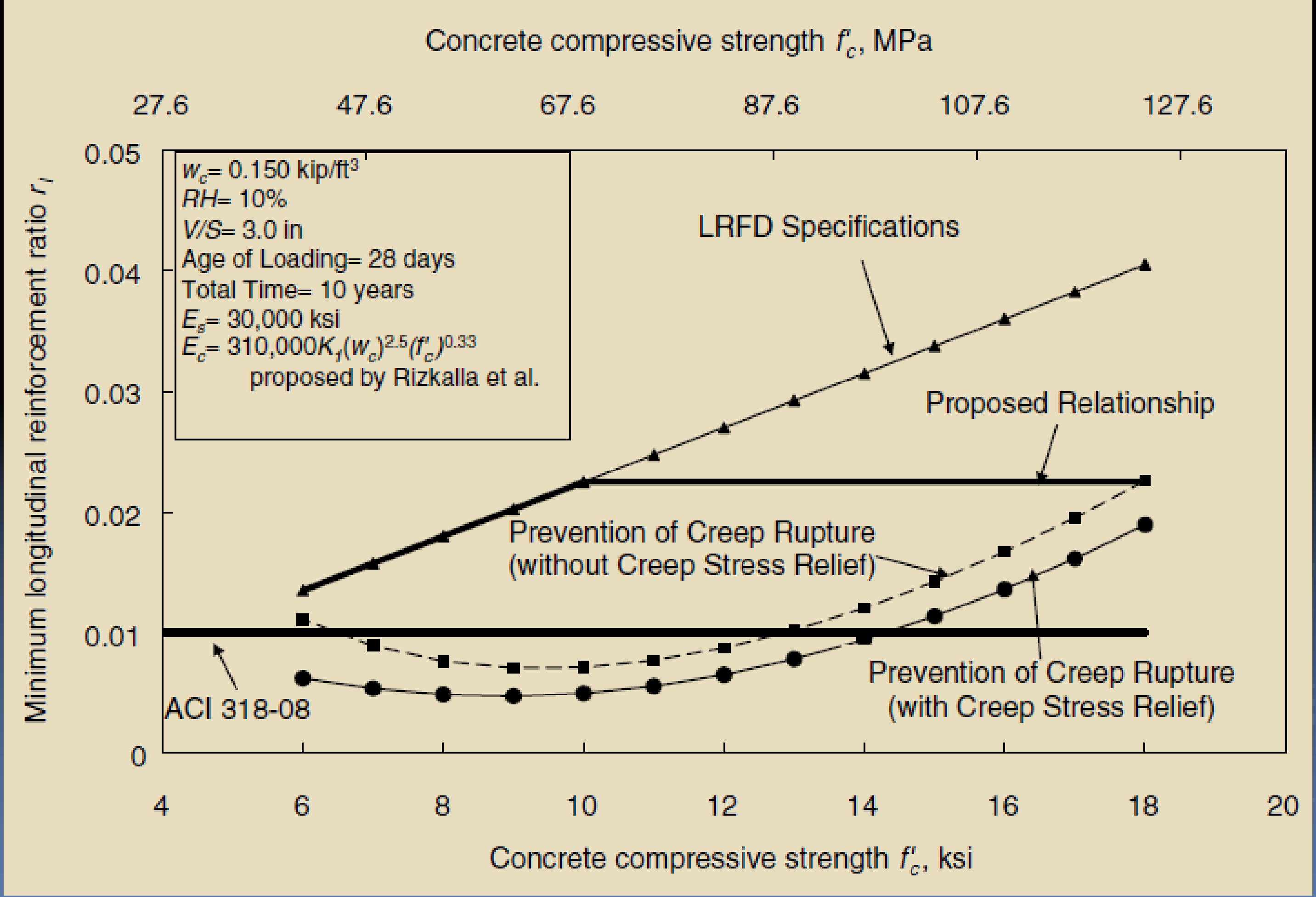
$A_\ell \geq 0.010A_g$

For members with section than required by loading:

$A_\ell \geq 0.005A_g$ based on a reduced effective area

PCI Journal – July-August 2010

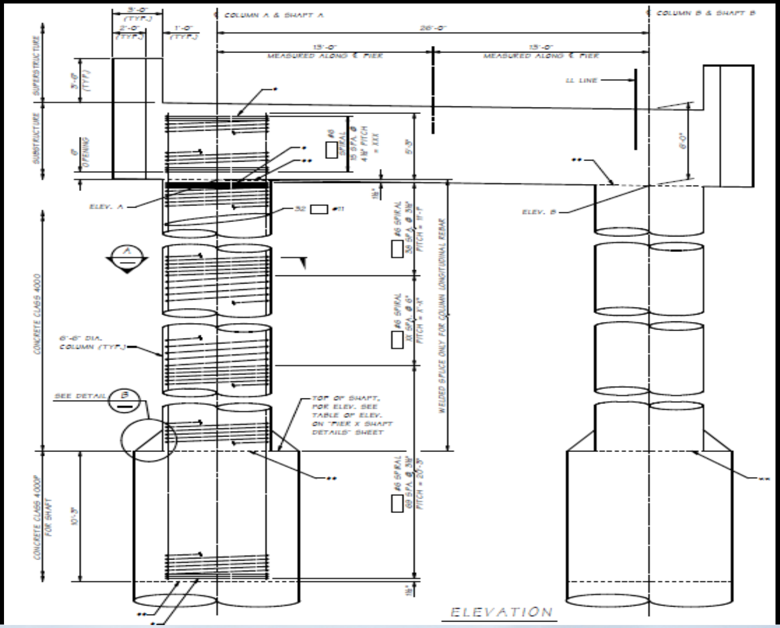
- Research has shown that circular columns perform adequately with lower longit reinf ratios
- Guide Spec, however does not distinguish between circular and non-circular columns.



Resolution:

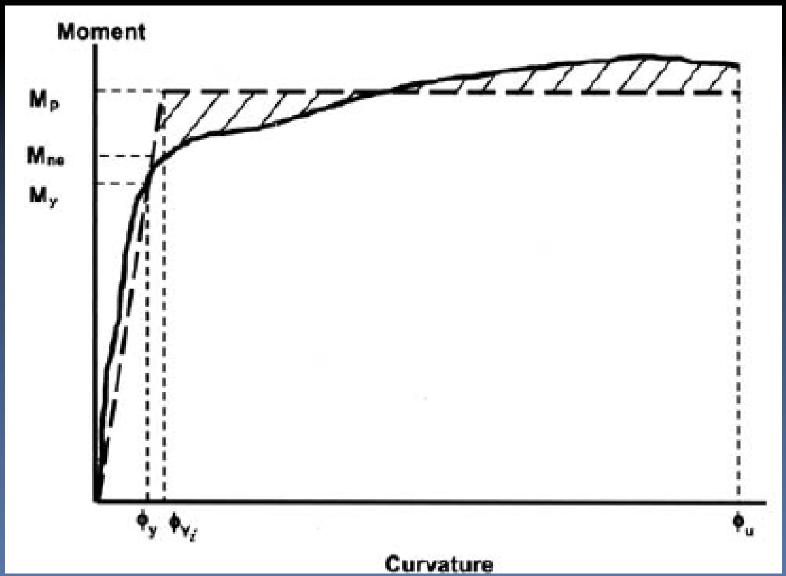
- Reduced the column longit. reinf ratio to 0.7%, which is below the code specified min. for SDC D of 1%.
- Displacement capacity and local member ductility are adequate for design event
- Service and Strength Limit States are satisfied
- This approach was used as opposed to a moment reducing hinge in order to maintain adequate member ductility

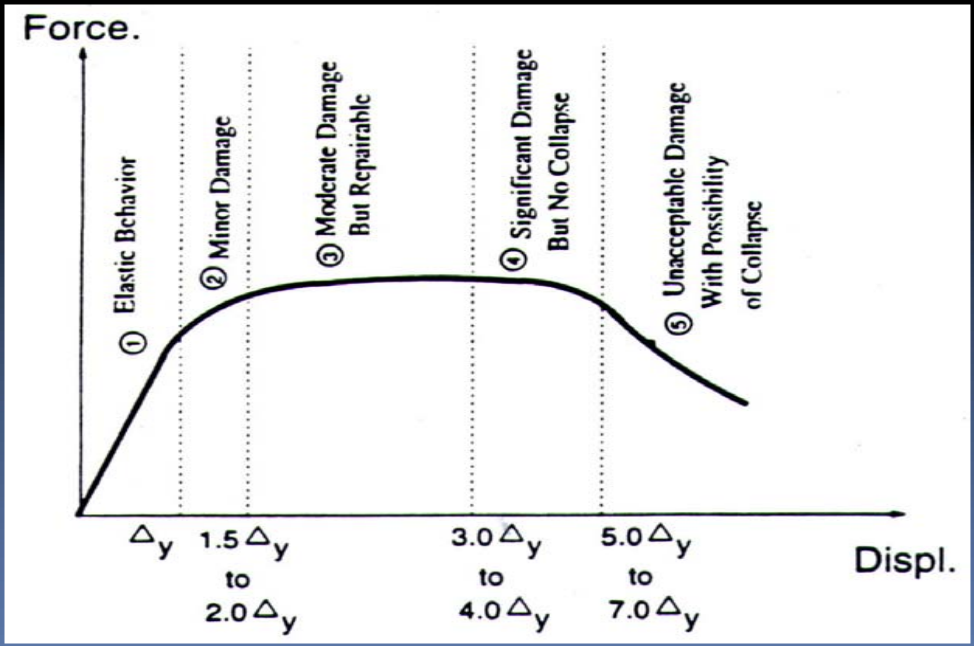
Case: Manette Bridge 6-span Spliced-girder bridge with 5 intermediate piers



Design Challenge:

- Columns remain elastic during design level seismic event.
- SGS do not address elastic design for column shear or foundation designs
- SGS 8.9-Requirements for Capacity-Protected Members.





SGS 3.3 - Earthquake-resisting Systems (ERS) Requirements For SDCs C AND D

The SGS allows three global seismic design strategies based on bridge types and system:

- **Type 1:** Design a ductile substructure with an essentially elastic superstructure
- **Type 2**—Design an essentially elastic substructure with a ductile superstructure
- **Type 3**—Design an elastic superstructure and substructure with a fusing mechanism at the interface between the two

SGS 8.9 - Requirements For Capacity Protected Members

- Capacity-protected members that are adjacent to the plastic hinge locations shall be designed to remain essentially elastic at plastic hinging stage. The expected nominal capacity, M_{ne}, *is used* using a *M-φ diagram.*

Resolution:

Design the columns for 1.2 times the elastic shear demand, design foundations for the elastic demands for flexure and 1.2 times the elastic shear demands.

SGS C4.11.1: Oversized Columns

- In some cases, because of architectural or for other reasons, at the discretion of the Owner, for SDC C or D, if columns are considered an integral part of the energy-dissipating system, but remain elastic at the demand displacement, the forces to use for capacity design of other components are taken in the range of about 1.2 to 2.0 times the elastic forces resulting from the demand displacement in lieu of the forces obtained from overstrength plastic hinging analysis.
- The choice of value “1.2 to 2.0” should include consideration of the importance of the structure.

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SGS C3.7: EQ + LL

- At the discretion of the Owner, the effects of LL may be combined with seismic loads. When live and seismic loads are considered concurrently, a LL factor up to γ_{EQ} = *0.5 is recommended for typical cases.*

- For Critical/Essential bridges, or those that carry rail traffic, a project-specific LL factor shall be considered.

- For computational ease, the effects of LL need not be considered in the pushover analysis for displacement capacity and ductility demand.

- Vehicular LL have not been observed to be in-phase with bridge structures during seismic events. The inertial effect of LL is negligible for the pushover and dynamic analyses for typical bridges in SDCs C and D.

Case 3: SR522 Snohomish River Bridge

1,800 ft long, curved steel plate girder bridge

Geotechnical and Hydraulics Conditions:

- Multiple layers of liquefiable soil, soft slay and artesian water at piers
- Shaft depth was recommended to be limited to 100 feet from the current ground surface

•River Migration: the 600 foot wide river may migrate to any of intermediate piers within river width.

Scour: As a result, river migration will wash out the top 27.5 foot soil and the local scour will further wash out additional 24 foot soil near the piers

Resolution 1– Multi Hazard:

Since the probability of a design EQ occurring with maximum scour event is low, therefore:

- **Extreme Event I: (l00 year event)**

  When scour is included with the skin resistance of the soil, 25% of the scour depth for the design flood shall be deducted from the resistance of the shaft.

- **Extreme Event II: (500 year event)**

  The loss of skin resistance for the full scour depth of the flood shall be considered when checking the axial capacity of the shaft

Group Reduction Factors for Bearing Resistance of Shafts

Soil Type	Shaft Group Configuration	Shaft Center-to-Center Spacing	Group Reduction factor, η
Cohesionless (e.g., sands, gravels and rocks)	Single row	2D	0.90
		3D or more	1.0
	Multiple row	2.5D	0.67
		3D	0.80
		4D or more	1.0
	Single and multiple rows	2D or more	1.0
	Single and multiple rows	2D or more	1.0
Cohesive (Clays, clayey sands, and glacial till)	Single or multiple rows	2D or more	1.0

SGS 8.9: Overstrength Factor

The calculated Plastic Hinge moment of the column and associated column shear from the pushover analysis are applied on the top of the shaft:

$M_{po} = 1.2\ M_p$ SGS 8.5

$M_{Design} = 1.25\ M_{po}$ SGS 8.12

With The Owner's Approval, The Factor of 1.25 May Be Reduced To 1.0 For The Liquefied Configuration.

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Seismic Design challenge:

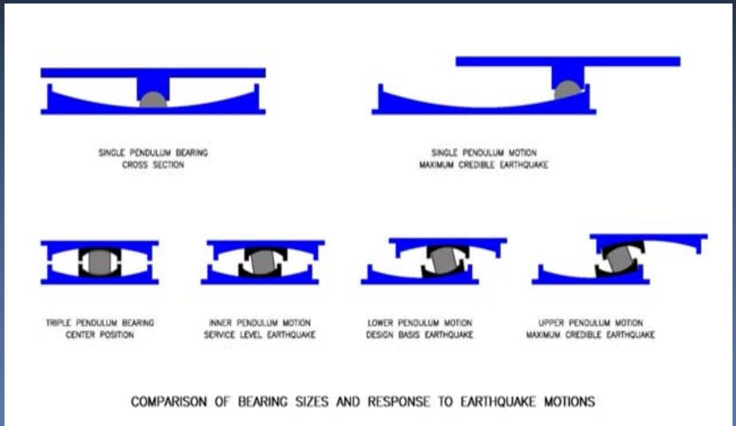
Using conventional Plastic Hinging requires to design shaft for the plastic moment and shear of the column. This design method requires

- 3% or more shaft longitudinal reinforcement (large bundled bars), Large hoops, High construction cost

Resolution: Use of Type 3 - Fusing

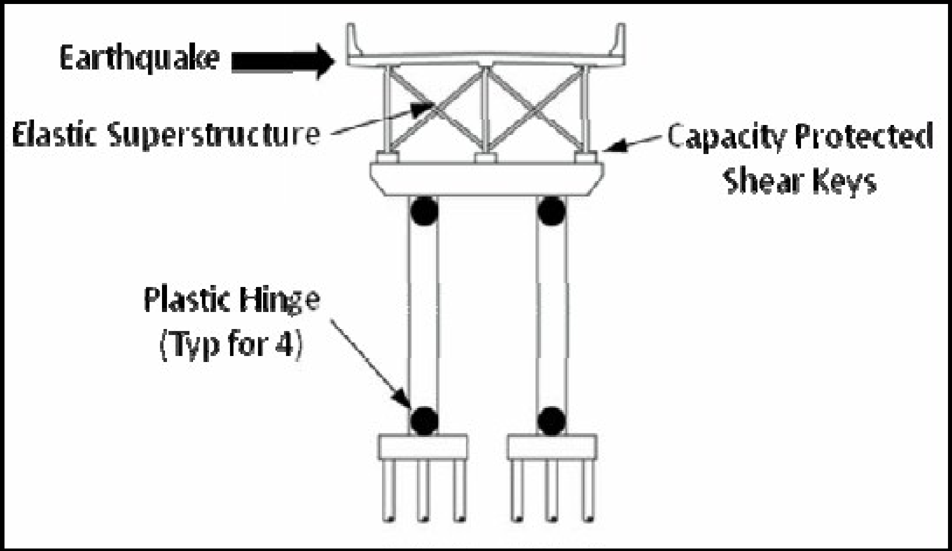
- By using the Isolation Bearing, the longitudinal reinforcements of the drilled shafts were reduced to 1%

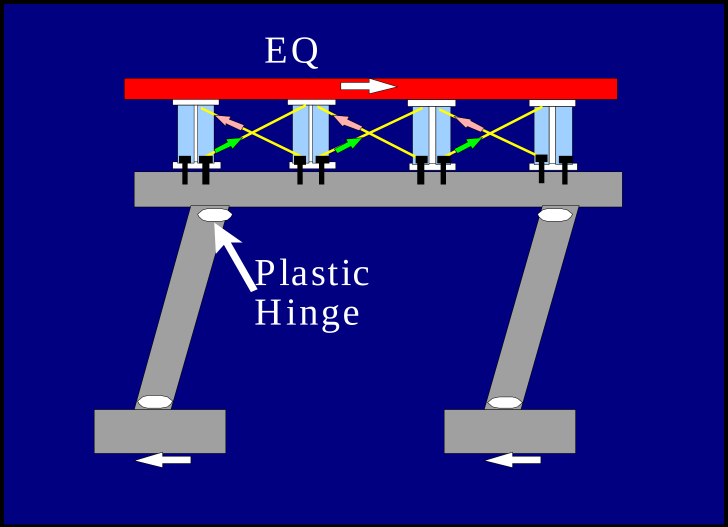
The Friction Pendulum Isolation Bearing was selected over the disc bearing to reduce the lateral force into substructure.



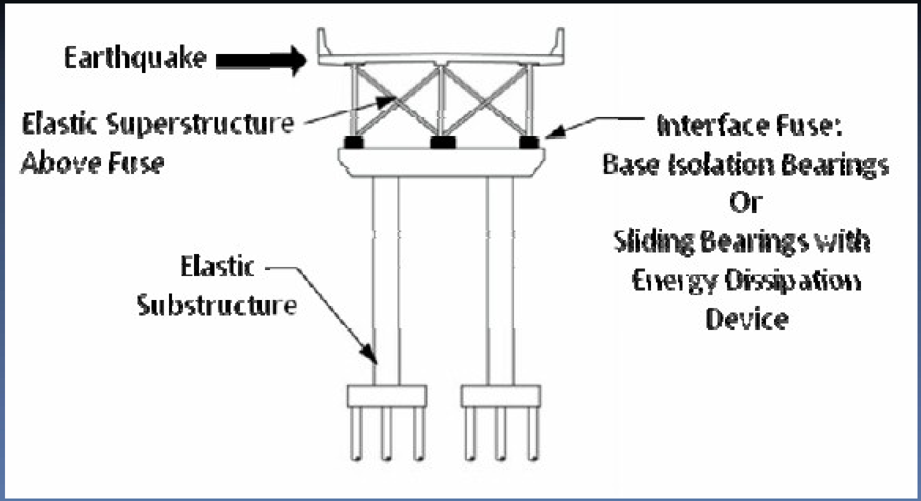
Global Design Strategies

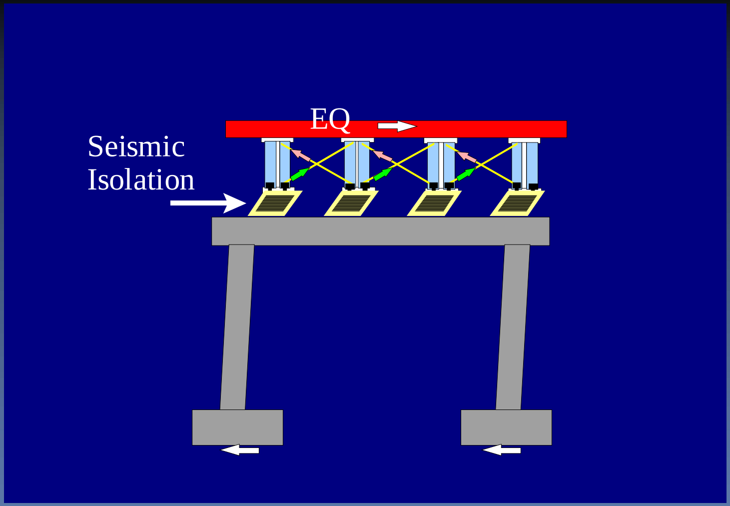
ype 1 - Ductile substructure with an essentially elastic superstructure





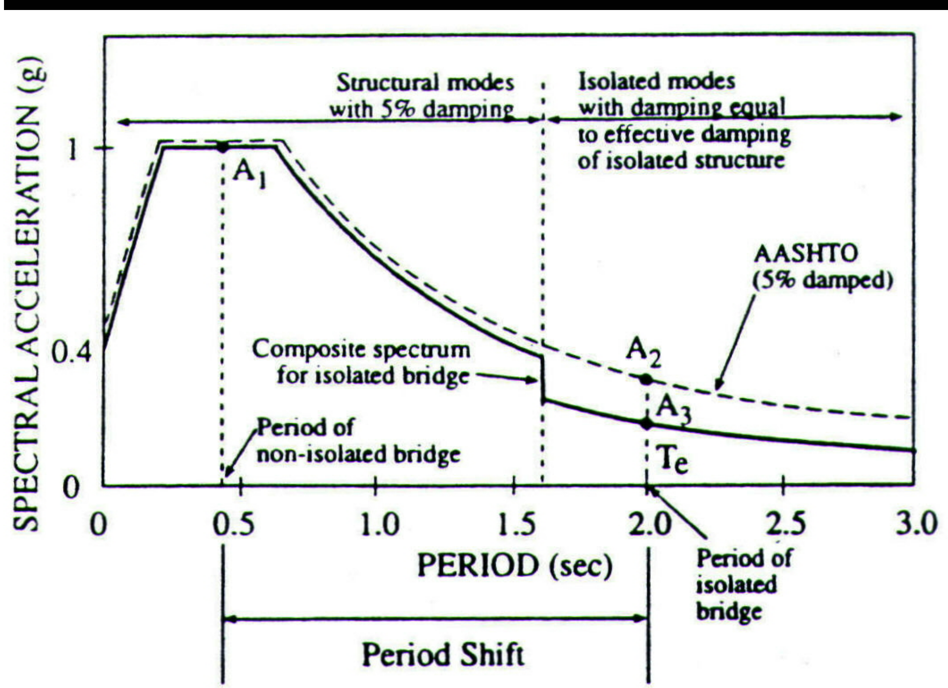
ype 3 - Design an elastic superstructure and substructure with a fusing mechanism at the interface.

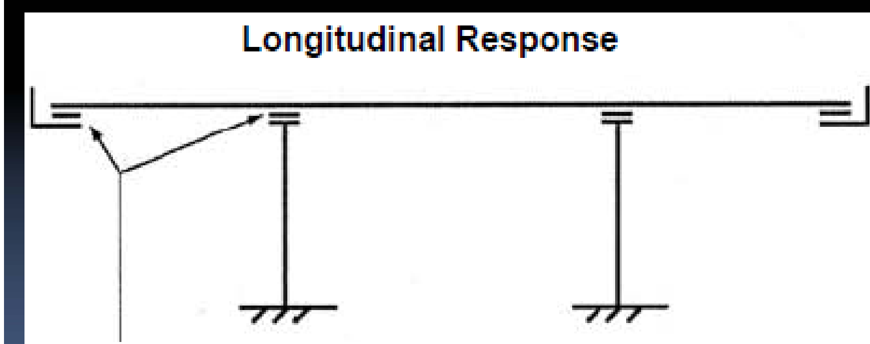




and Substructure with a Fusing Mechanism in Between

- The intent of seismic isolation bearings is to increase the fundamental period of vibration such that the structure is subjected to lower earthquake forces.
- The reduction in force is accompanied by an increase in displacement demand that must be accommodated within the isolation system.

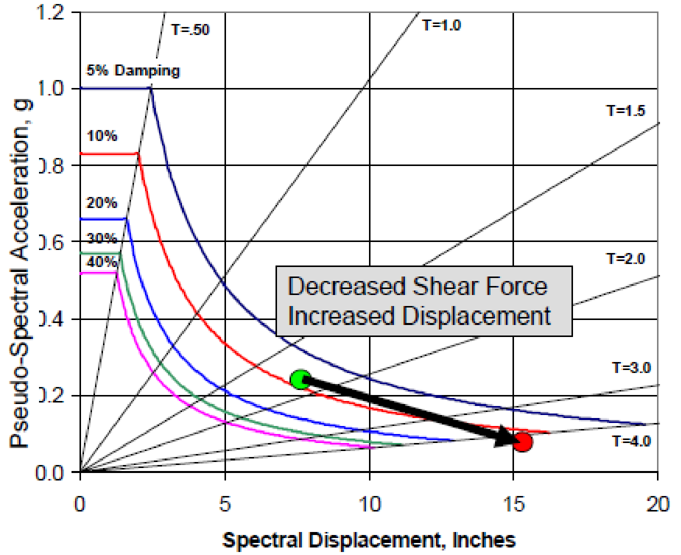




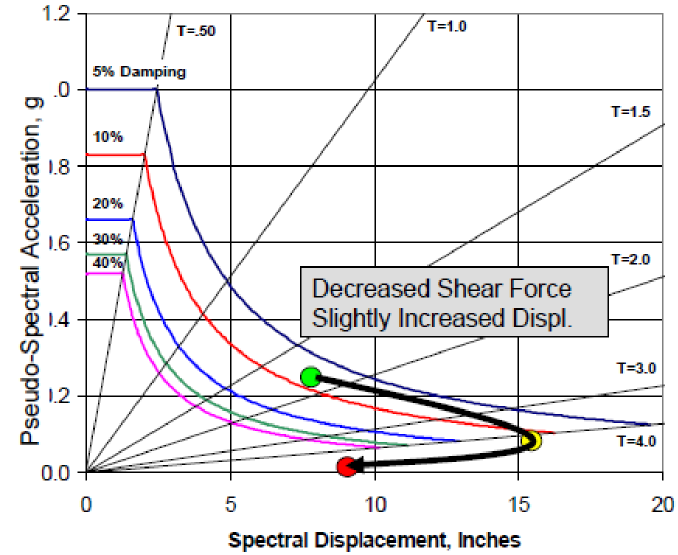
- Isolation bearings accommodate full displacement
- Abutment not required as part of ERS

Basic Principle of Seismic Isolation Design

Effect of Seismic Isolation (ADRS Perspective)

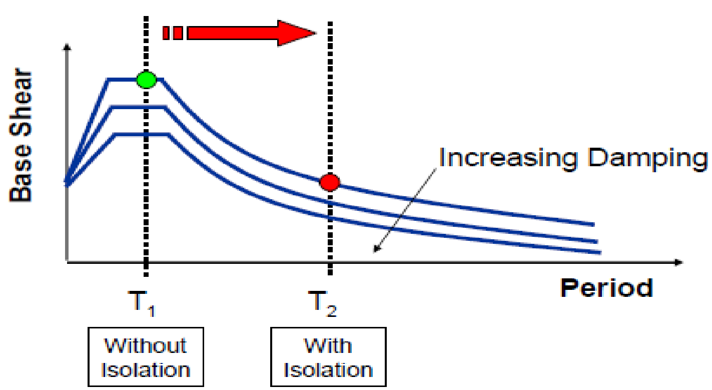


Effect of Seismic Isolation with Supplemental Dampers (ADRS Perspective)

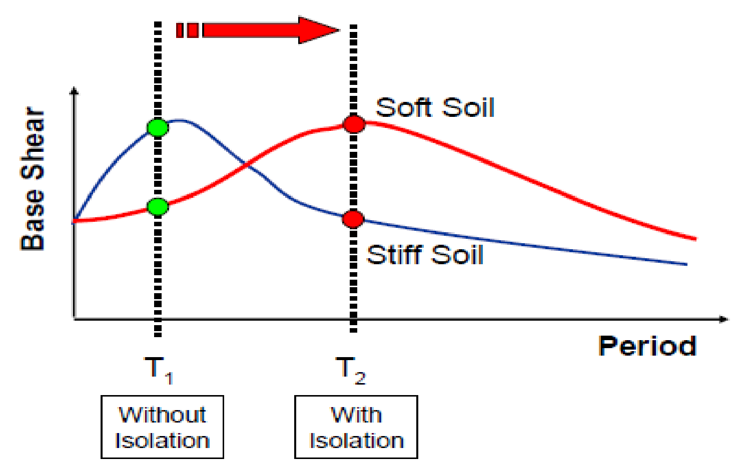


Effect of Seismic Isolation (Acceleration Response Spectrum Perspective)

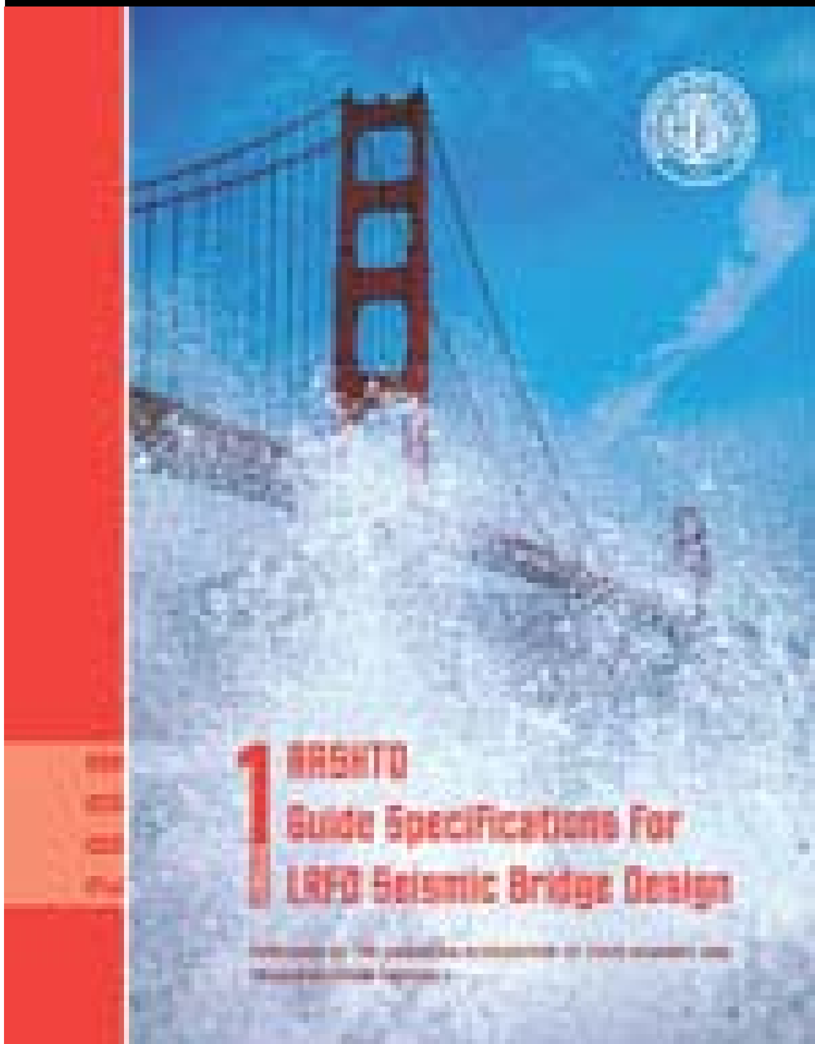
Increase Period of Vibration of Structure to Reduce Base Shear

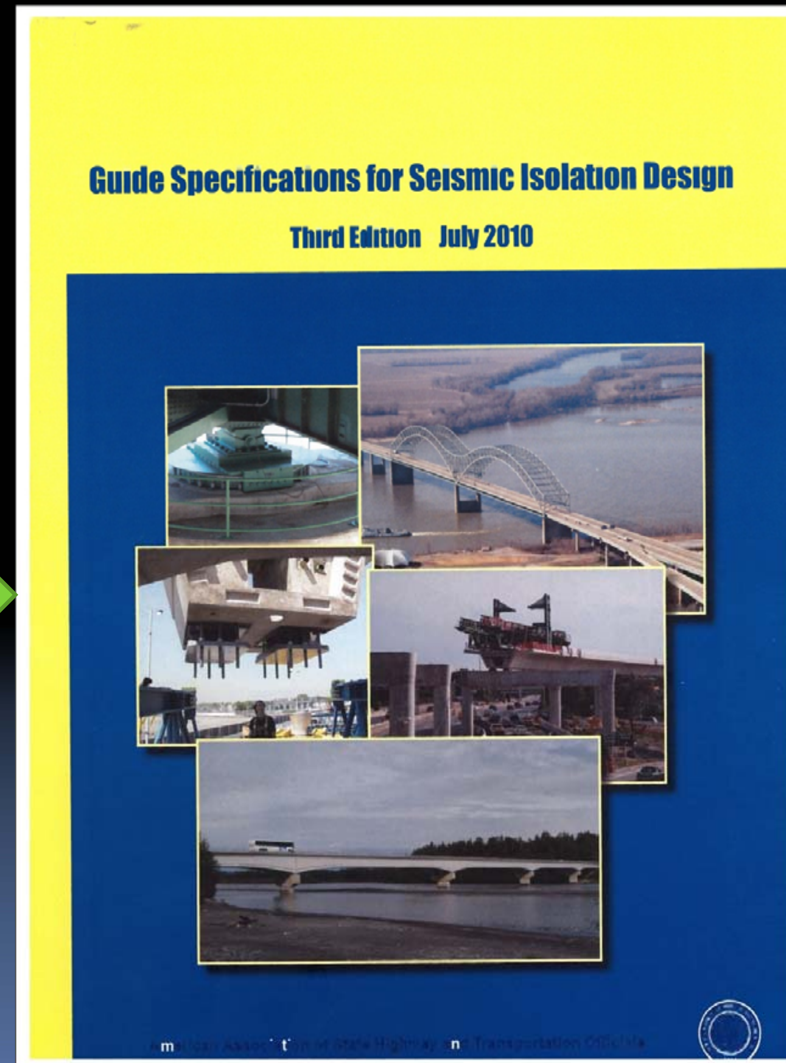


Effect of Soil Conditions on Isolated Structure Response

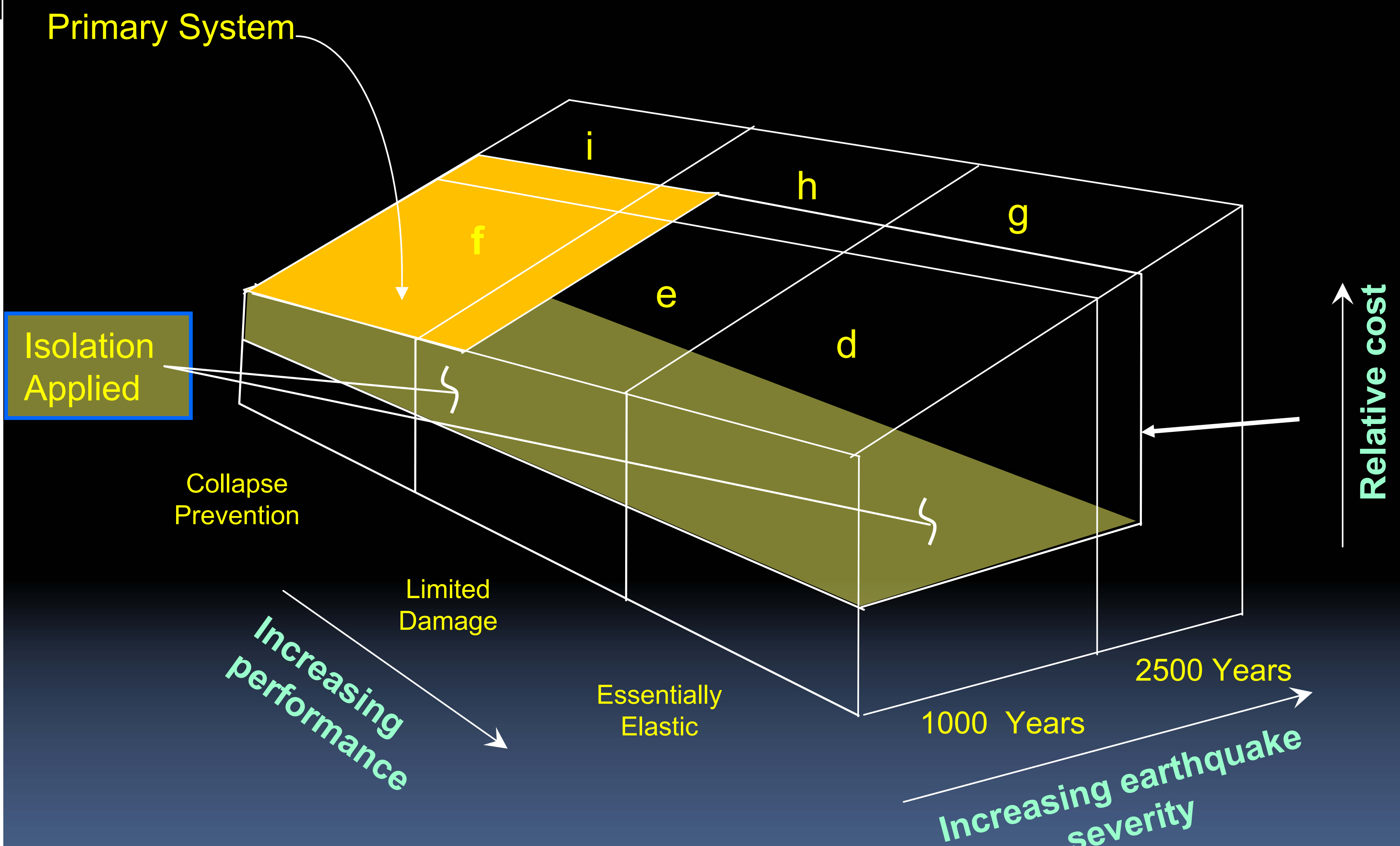


Isolation bearings are designed per AASHTO "Guide Specs for Seismic Isolation Design"





Cost-Benefit of Seismic Isolation Bearing



Calibration Objectives

Cost Analysis: Savings on Drilled Shaft (P2-8) Construction Cost by Using Isolation Design

	Length (ft)	Total cost ($)	Savings($)
Rebar for Original Design	1980	1696464	
Structure Steel	1980	356400	
Total Steel Cost for Isolation Design	1515	440105	$ (1,612,759)
Saving on Reduced Shaft Length	163	473678	$ (473,678)
Total Gross Saving			**$ (2,133,800)**
Isolation Bearing Cost		576800	
Disc Bearing Cost		399000	
Additional cost for isolation bearings		177,800	**$ 177,800**
Net saving			**$ (1,956,000)**

WSDOT: Design Policy Memorandum

- Type 1 earthquake-resisting system (ERS) as specified in the AASHTO Guide Specifications for LRFD Seismic Bridge Design SGS3.3 is the preferred ERS System for seismic design of bridges.
- Type 3 ERS, with elastic superstructure and substructure and a fusing mechanism between the two, may be considered only if Type 1 strategy is not suitable and Type 3 strategy has been deemed necessary for accommodating seismic loads.

Isolation Bearing – Continue

- The decision for using isolation bearings should be made at the early stage of project based on the complexity of bridge geotechnical and structural design.

  A cost-benefit analysis comparing Type 1 design vs. Type 3 design with isolation bearings shall be performed and submitted for approval.

  The Designer needs to perform two separate designs, one with and one without seismic isolation bearings.

Isolation Bearing – Continue

- Use of seismic isolation bearings are not recommended for conventional short and medium length bridges, or bridges with geometrical complexities.
- Use of isolation bearings may not be beneficial for:
  - concrete bridges under 700 feet long,
  - steel bridges under 800 feet long,
  - bridges with skew angles exceeding 30 degrees,
  - bridges with geometrical complexities, variable width, and drop-in spans.

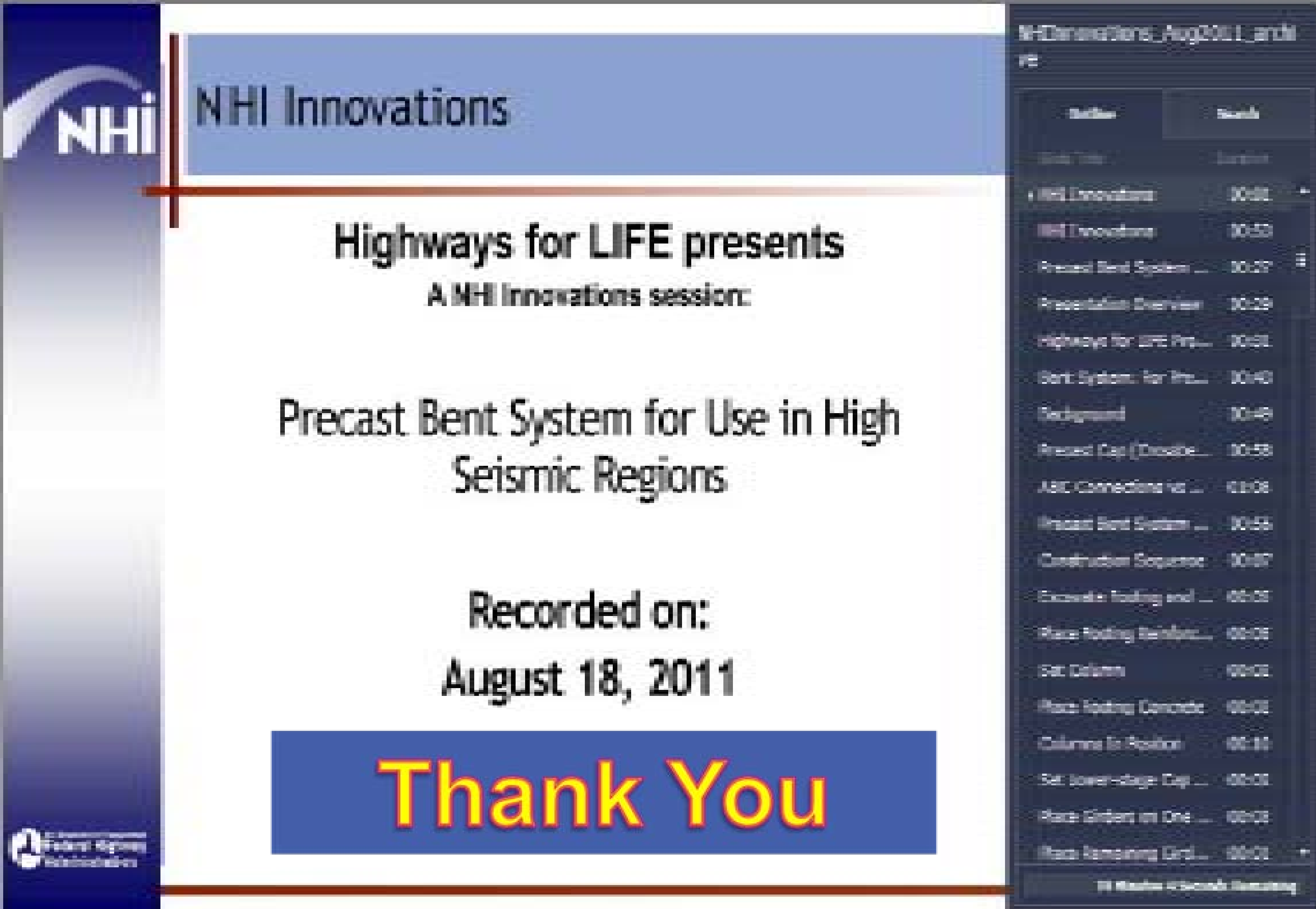
Isolation Bearing – Continue

The Cost-benefit Analysis Shall Include:

- Impact Of The Initial And Final Design Time On The Project Delivery Schedule
- Life-cycle Cost Of Additional And Specialized Bearing Inspections/Testing
- Potential Cost Impact For Bearings And Expansion Joints Replacements
- Issues Related To Long-term Performance And Maintenance, And
- Need For Large Movement Expansion Joints

Isolation Bearing – Continue

- Designer shall send a set of preliminary design and specification requirements to at least three seismic isolation bearing suppliers.
- Sole source isolation bearing supplier may be considered upon owner's approval.
- Suppliers shall provide maintenance and inspection requirements to ensure the isolators will function properly during design life and after seismic events.
- The contract plans shall include bearing replacement methods and details.
- The response modification factors (R-factors) of the Guide Specifications for Seismic Isolation Design Article 6 shall not be used



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