Recommended LRFD Guidelines for the Seismic Design of Highway Bridges

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Recommended LRFD Guidelines for the Seismic Design of Highway Bridges

For: *AASHTO LRFD Bridge Design Specifications*

(Load and Resistance Factor Design)

Sponsors:

- National Cooperative Highway Research Program (NCHRP) NCHRP 12-49
- Federal Highway Administration (FHWA)

Prepared by:

- ATC/MCEER Joint Venture
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Where The Process Stands

- Provisions for LRFD spec developed
- Stand-alone guidelines developed
- Trial designs / limited use as resource
- Barriers to AASHTO adoption:
  - Number of bridges in higher zones too large
  - Return period (2500 years) too long
  - Guidelines too complex
- Next step?

Key Concepts

- National hazard maps, site factors, spectra
- Performance objectives and design earthquakes
- Emphasis on capacity design principles
  - Selected yielding / damage sites
  - Essentially elastic response elsewhere
- Seismic Design and Analysis Procedures (SDAP)
- Improved foundation, abutment and liquefaction design procedures

Design Earthquakes

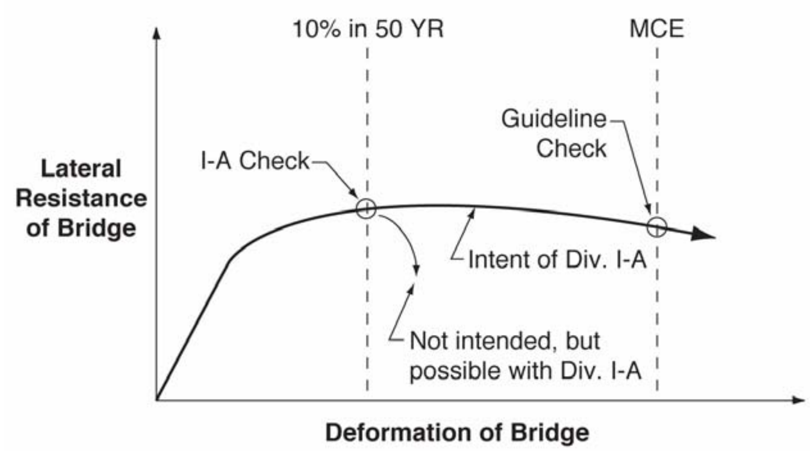
- Rare Event
  - 3 % probability of exceedance (PE) in 75 years (2500-year return period)
  - Deterministically capped near active faults
- Frequent Event
  - 50 % PE in 75 years (100–year return period)
  - Similar to flood and associated performance objectives
- Consistent with retrofit definitions
  - Probability of exceedance and not return period

Performance Objectives

	Performance Objective	
Probability of Exceedence	Life Safety	Operational
Rare EQ SL 3%/75yr *D*	Significant disruption *Significant*	Immediate *Minimal*
Freq EQ SL 50%/75yr *D*	Immediate *Minimal*	Immediate *None*

SL = Service Level *D = Damage*

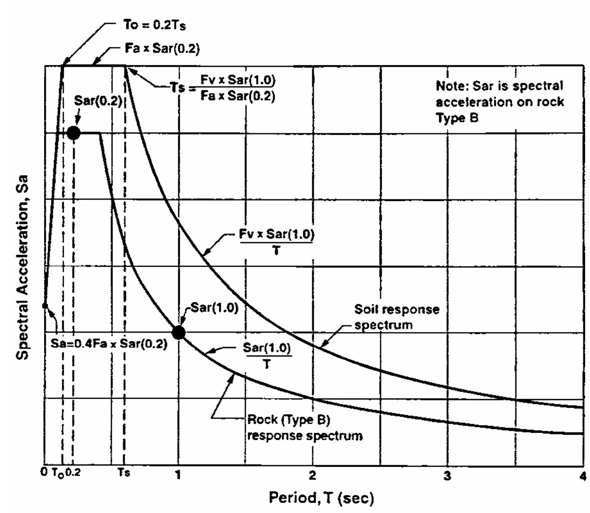
Philosophy Behind the Guidelines



Logic Behind the Guidelines

- Seismic hazard is function of mapped acceleration and soil
  - 0.2-second spectral acceleration (S_s)
  - 1-second spectral acceleration (S_1)
  - Site coefficients (F_a and F_v)
- Increasing rigor in the provisions with hazard
  - Seismic Analysis and Design Procedures (SDAP)
  - Seismic Detailing Requirements (SDR)

Response Spectrum Construction



Seismic Hazard Levels

Seismic Hazard Level	Value of F_vS_1 (1-second)	Value of F_aS_s (0.2 –second)
I	$F_vS_1 \leq 0.15$	$F_aS_s \leq 0.15$
II	$0.15 < F_vS_1 \leq 0.25$	$0.15 < F_aS_s \leq 0.35$
III	$0.25 < F_vS_1 \leq 0.40$	$0.35 < F_aS_s \leq 0.60$
IV	$0.40 < F_vS_1$	$0.60 < F_aS_s$

Design Options

Seismic Design and Analysis Procedures (SDAP)
and Seismic Design Requirements (SDR)

Seismic Hazard Level	Life Safety		Operational	
	SDAP	SDR	SDAP	SDR
I	A1	1	A2	2
II	A2	2	C/D/E	3
III	B/C/D/E	3	C/D/E	5
IV	C/D/E	4	C/D/E	6

"No Seismic Analysis" SDAP B

- 'Regular' bridges in lower seismic hazard areas
- Bridge does not require seismic demand analysis
- Capacity design procedures used for detailing columns and connections
- No seismic design requirements for abutments

Capacity Spectrum SDAP C

- Conceptually similar to Caltrans' displacement design method
- May be used for 'very regular' structures
- Period of vibration does not need to be calculated
- Designer sees explicit trade-offs between design forces and displacements

Elastic Response Spectrum SDAP D

- Same as current code, uses either the uniform load or multi-mode method of demand analysis.
- 'R-Factor' design force approach, similar to current code.
- Requires capacity design approach for superstructure, column shear, connections, abutments and foundations.

“Pushover” Analysis – SDAP E

- Perform multi-mode analysis, use 50% higher R-Factor for initial design, then check plastic rotations and displacements with pushover.
- Quantifies expected deformation demands in columns and foundations
- Highest R-Factors for column design
- Required for limited ductility systems so that actual demands on the elements are known.

Capacity Design Principles

- Include formal identification of earthquake resisting system
- Limit yielding/damage to preferred elements (e.g. columns – above ground)
- Reduce capacity if yielding not confined to preferred elements (e.g. drilled shafts - below ground)
- Increase capacity if pushover assessment used

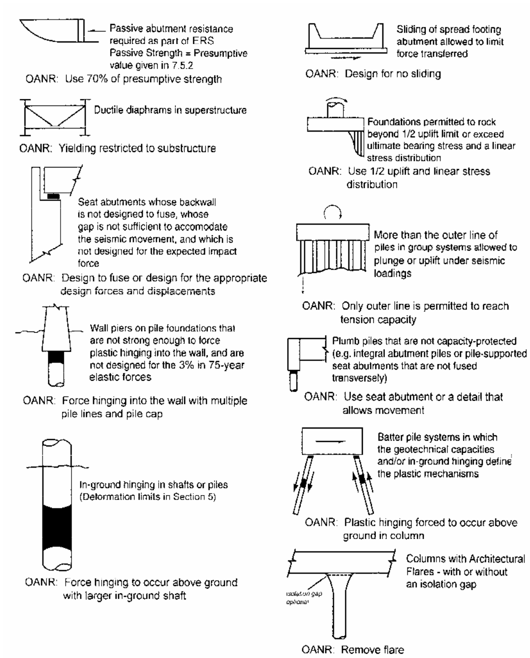
Earthquake Resisting Systems (ERS) and Elements (ERE)

Three categories:

(1) Permissible (Preferred)
(2) Permissible with owner's permission
(3) Not recommended

ERE Example

Permissible Earthquake Resisting Elements that Require Owner's Approval



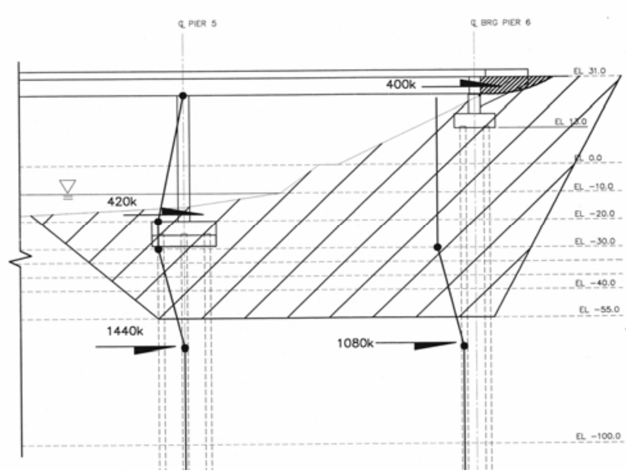
Foundations and Abutments

- Guidance for development of soil springs
- Guidance for assessment of performance
- Recognition of the beneficial contribution of abutment resistance
- Soil deformation effects considered in terms of structural and operational implications
- Design and detailing for liquefaction effects

Liquefaction Assessment

- State-of-the-art procedures for estimating liquefaction potential
- Quantification of liquefaction effects
  - lateral flow or spreading of approach fills
  - settlements of liquefied soils
- Use of ground improvement and pile resistance to limit soil movement
- Acceptance of plastic hinging in piles

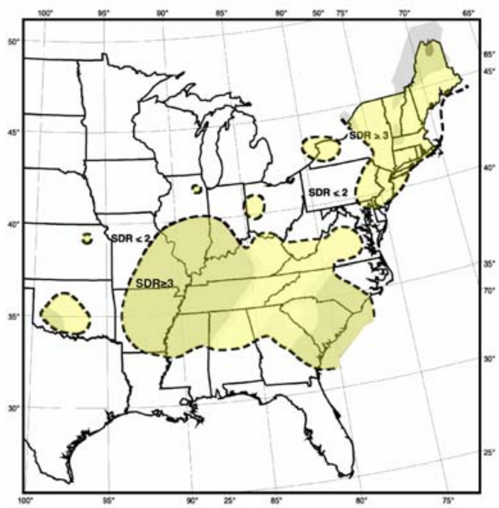
Ground Movement vs. Structure Resistance Mechanisms



Parameter Study, Trial Designs and Design Examples

- 2400 simplified substructure designs
- 19 trial designs by state DOTs
- 2 design examples
- Broad, nationwide data sets included
- Costs similar to or only moderately higher (+/- 10%) than those by current provisions

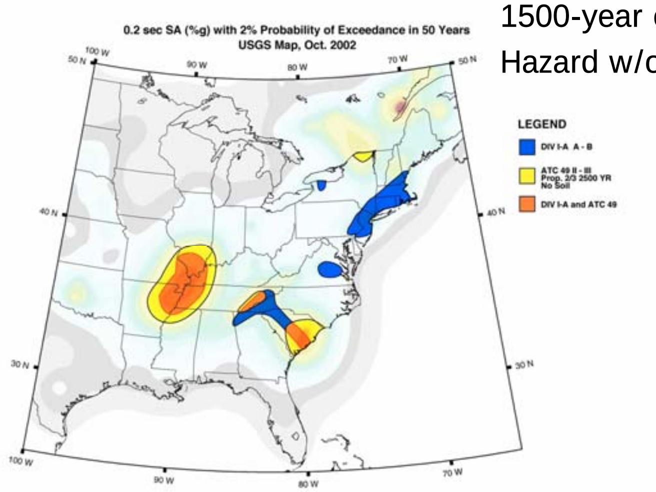
Original Zone of Higher Seismic Design Requirements – Eastern US



A Possible Revision to Seismic Design Boundaries – Eastern US

1500-year event

Hazard w/o soil factor



Conclusions

- Guidelines include many of the current "best practices" (a number of which were developed for special bridges)
- Design provisions are nationally consistent
- Designs produced have reasonable costs
- Guidelines provide reasonable platform for seismic design specifications

Thank You