

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

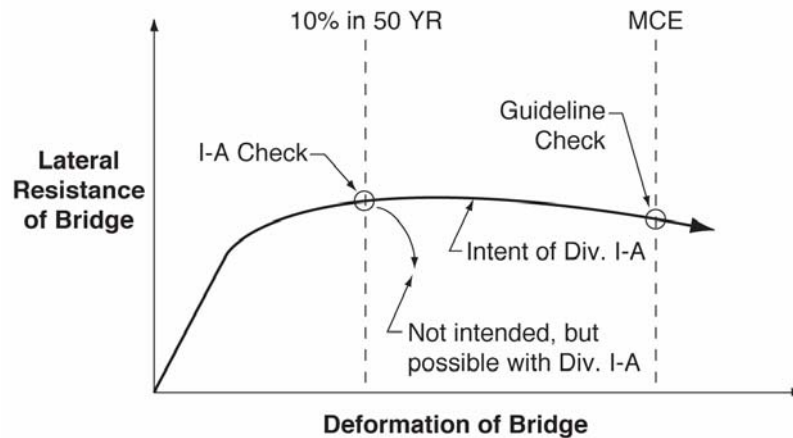
Performance Objectives

| | | Performance Objective | |
|---------------------------|----------------|--|-----------------------------|
| Probability of Exceedance | | Life Safety | Operational |
| Rare EQ 3%/75yr | SL <i>D</i> | Significant disruption <i>Significant</i> | Immediate <i>Minimal</i> |
| Freq EQ 50%/75yr | SL <i>D</i> | Immediate <i>Minimal</i> | Immediate <i>None</i> |

SL = Service Level

D = Damage

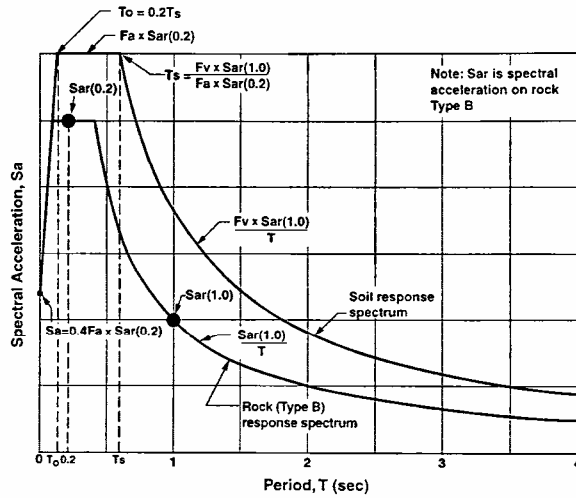
Philosophy Behind the Guidelines



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 $F_v S_{v1}$ (1-second) | Value of $F_a S_s$ (0.2-second) |
|----------------------|----------------------------------|---------------------------------|
| I | $F_v S_{v1} \leq 0.15$ | $F_a S_s \leq 0.15$ |
| II | $0.15 < F_v S_{v1} \leq 0.25$ | $0.15 < F_a S_s \leq 0.35$ |
| III | $0.25 < F_v S_{v1} \leq 0.40$ | $0.35 < F_a S_s \leq 0.60$ |
| IV | $0.40 < F_v S_{v1}$ | $0.60 < F_a S_s$ |

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

Passive abutment resistance required as part of ERS
 Passive Strength = Presumptive value given in 7.5.2

OANR: Use 70% of presumptive strength

Ductile diaphragms in superstructure

OANR: Yielding restricted to substructure

Seat abutments whose backwall is not designed to fuse, whose gap is not sufficient to accommodate the seismic movement, and which is not designed for the expected impact force

OANR: Design to fuse or design for the appropriate design forces and displacements

Wall piers on pile foundations that are not strong enough to force plastic hinging into the wall, and are not designed for the 3% in 75-year seismic forces

OANR: Force hinging into the wall with multiple pile lines and pile cap

In-ground hinging in shafts or piles (Deformation limits in Section 5)

OANR: Force hinging to occur above ground with larger in-ground shaft

Sliding of spread footing abutment allowed to limit force transferred

OANR: Design for no sliding

Foundations permitted to rock beyond 1/2 uplift limit or exceed ultimate bearing stress and a linear stress distribution

OANR: Use 1/2 uplift and linear stress distribution

More than the outer line of piles in group systems allowed to plunge or uplift under seismic loadings

OANR: Only outer line is permitted to reach tension capacity

Plumb piles that are not capacity-protected (e.g. integral abutment piles or pile-supported seat abutments that are not fused transversely)

OANR: Use seat abutment or a detail that allows movement

Batter pile systems in which the geotechnical capacities and/or in-ground hinging define the plastic mechanisms

OANR: Plastic hinging forced to occur above ground in column

Columns with Architectural Flares - with or without an isolation gap

OANR: Remove flare

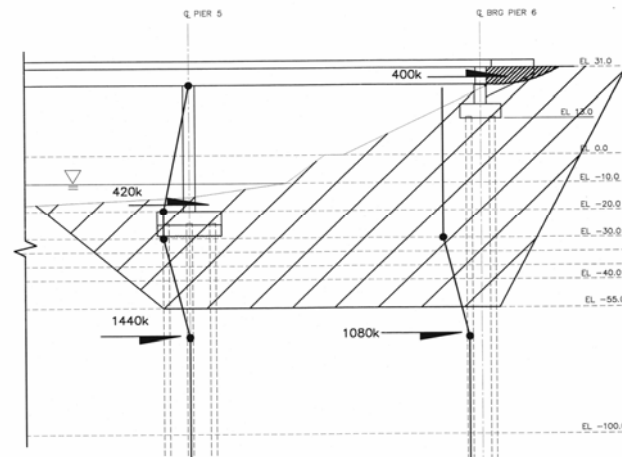
Foundations and Abutments

- ◆ 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

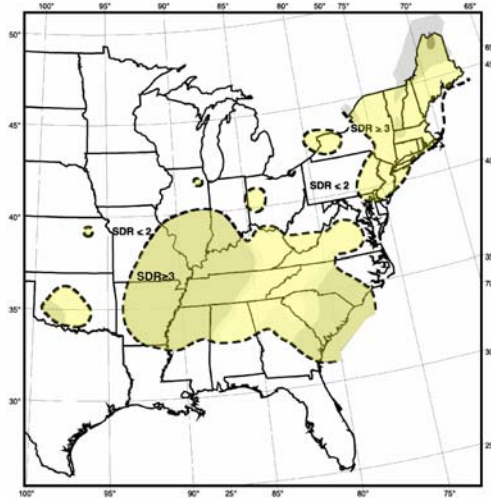
Ground Movement vs. Structure Resistance Mechanisms



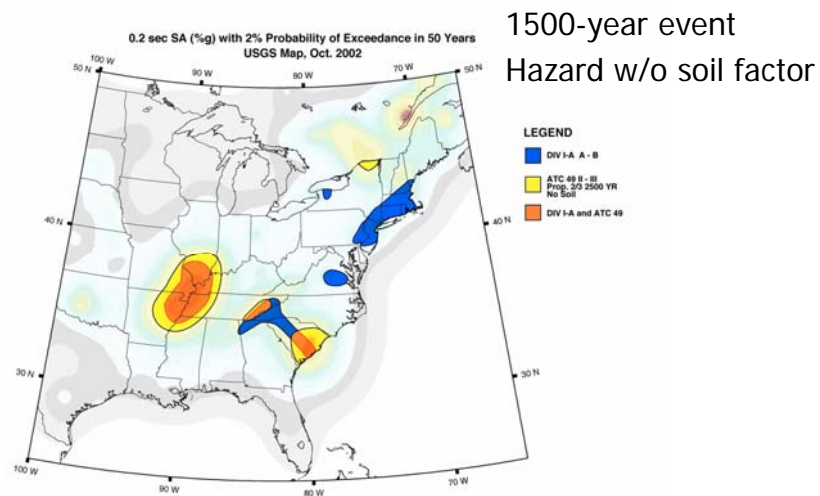
Parameter Study, Trial Designs and Design Examples

- ◆ 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



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
