DAVID EVANS AND ASSOCIATES INC.

# Implementation of Risk-Targeted Ground Motion Approach for Seismic Design of Concrete Bridges

Presented by

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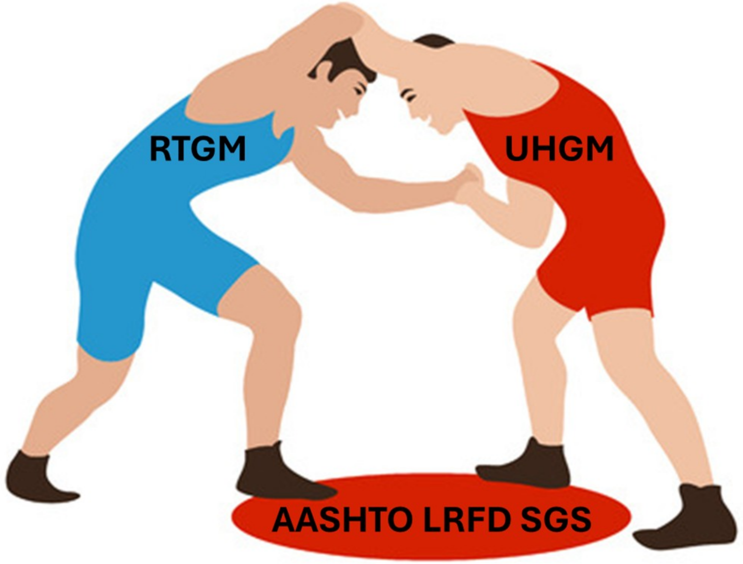
IABEE

*The Fifth International Bridge Seismic Workshop (5IBSW)*
*Hunan University, Changsha, China, June 5-7, 2026*

# Presentation Overview

1. Overview of AASHTO LRFD Seismic Bridge Design Specifications
   - Uniform Hazard Ground Motions (UHGM)
   - Risk-Targeted Ground Motions (RTGM)
2. UHGM and RTGM Design Comparison



# UHGM vs. RTGM

**Key Aspects of Uniform Hazard vs. Risk-Targeted Ground Motions**

- **Uniform Hazard Ground Motions (UHGM):** Traditionally, design maps provided ground motion amplitudes with a specific probability of exceedance.
- **Risk-Targeted Ground Motions (RTGM):** RTGM are derived by integrating the whole seismic hazard curve with a "notional" collapse fragility curve.

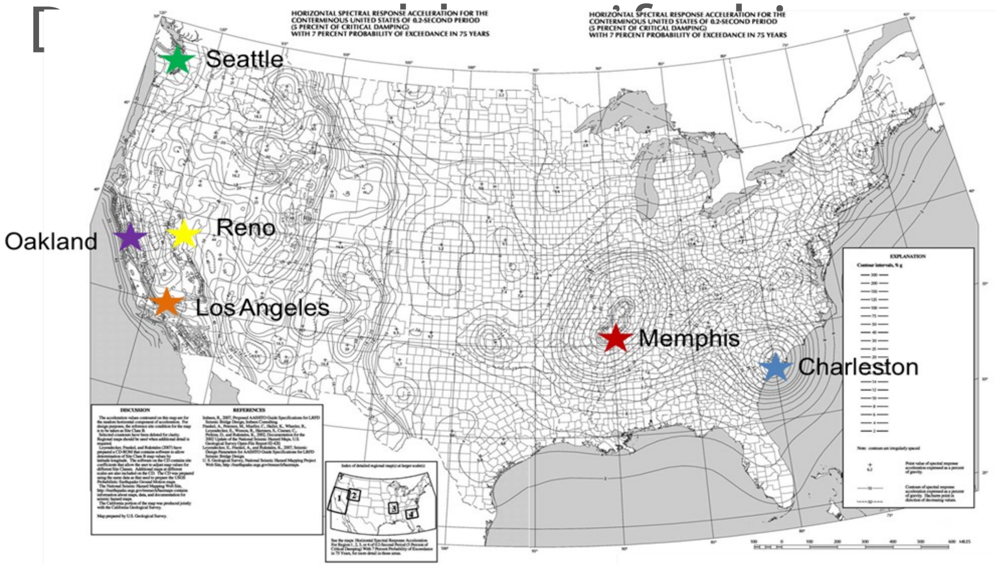
# Difference Between Seismic Risk and Hazard

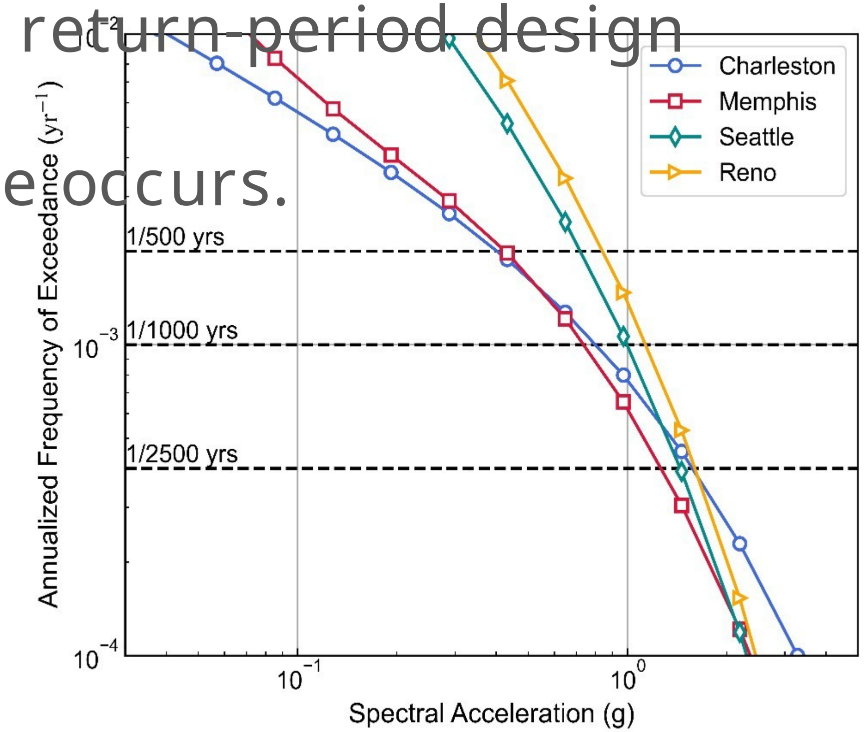
- **Seismic hazard** is given by the probability that an earthquake demand parameter, such as **peak ground acceleration or spectral acceleration, at a specific site will be exceeded** over a defined time of exposure.
- **Seismic risk,** relates to the likelihood that damage or loss will occur. Risk probabilities usually represent a level of **damage to a structure that is expected to be exceeded** over a defined time of exposure.

Both UHGM and RTGM are defined in terms of a probability of exceedance over a time window, but **seismic risk evaluates damage or loss**, whereas seismic hazard evaluates **ground shaking intensity**.

# Problem with Uniform Hazard Ground Motion (UHGM)

- A single return-period on the hazard curve is chosen for design
- Ignores variation with location.
- Risk is unequal across the U.S. - Single return-period design cannot account for these variations.
- D earthquake occurs.

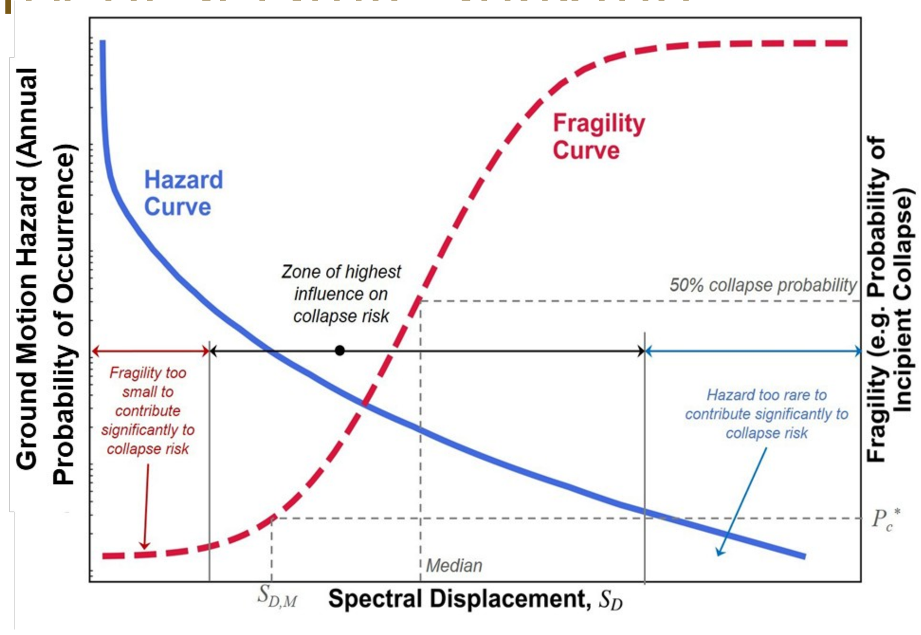


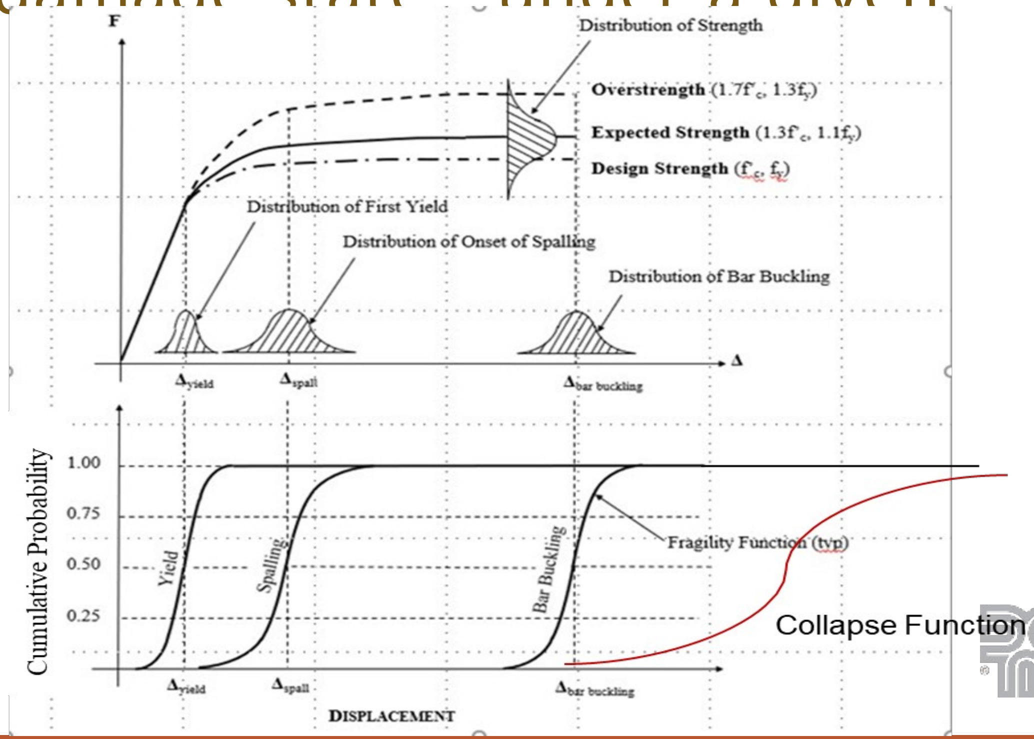



# Risk-Targeted Ground Motions (RTGM)

**RTGM is a Combination of** <u>Seismic Hazard</u> **and** <u>Structural Fragility</u>

In bridge seismic design, fragility refers to the probability to reach or exceed a specific level of damage, or a "damage state," under a given intensity of seismic shaking.



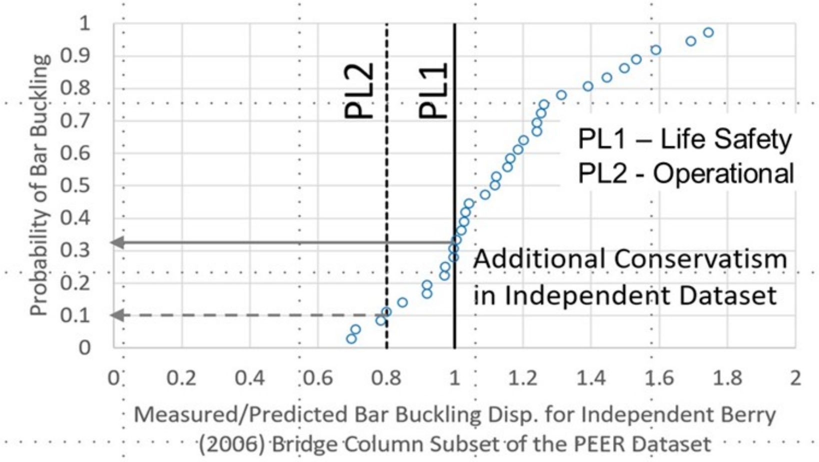



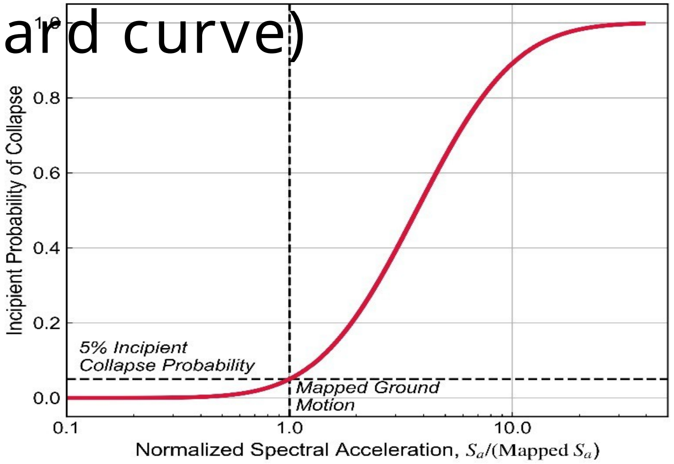
# RTGM – Fragility Function

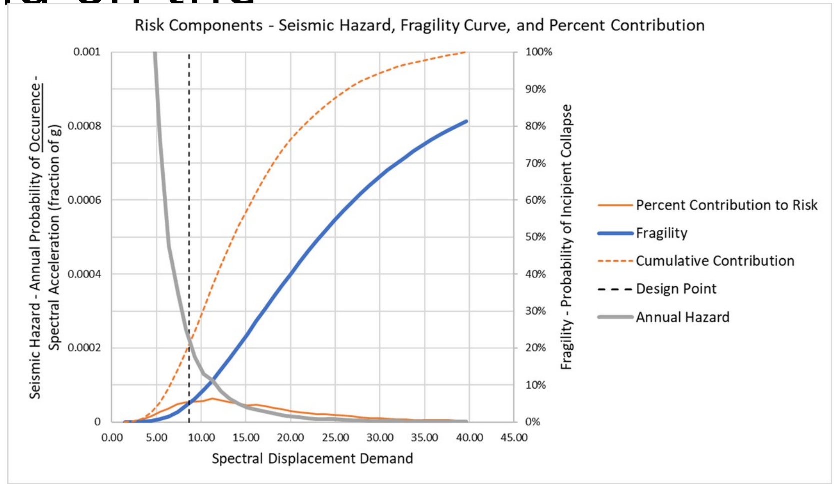
In RTGM the design ground motion is varied to achieve a target risk level:

$$R = \int_0^{\infty} Fr(a)\frac{dH(a)}{da}da$$

where R = Risk, Fr = Fragility, H = Hazard and "a" is spectral acceleration (could be spectral displacement depending on the hazard curve)



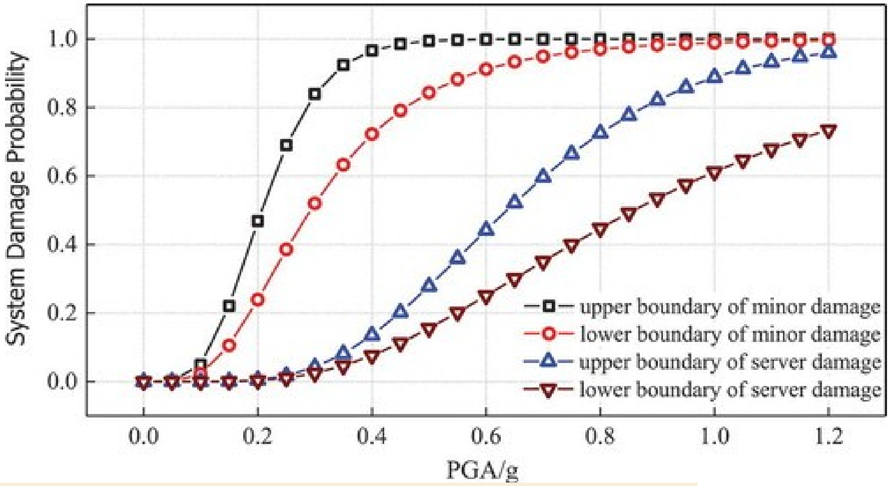



# Motivation for RTGM

- Significant Improvements in Hazard Estimation
- Geotechnical input for Soil effects, Site factors, Multi-period accelerations
- Consideration for Attenuation and Basin effects
- Reductions in design motions in eastern US
- ASCE 7 recently moved to RTGM

| Location | Mult for 1.5% | Design Sd(1) | Prob for UHS | Des Sd(1) UHS |
|---|---|---|---|---|
| Oakland, CA | 0.95 | 11.7” | 1.3 % in 75 yrs | 12.3” |
| Seattle, WA | 1.05 | 8.7” | 1.70 % | 8.2” |
| Memphis, TN | 1.22 | 4.5” | 2.12 % | 3.7” |
| Charleston, SC | 1.54 | 4.3” | 2.77 % | 2.8” |

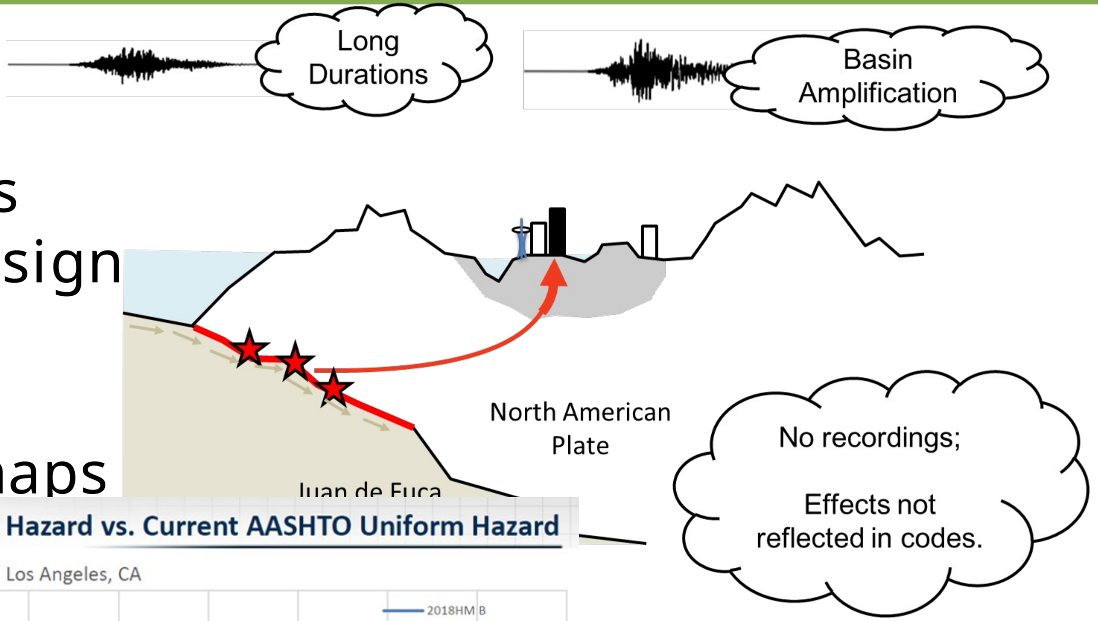


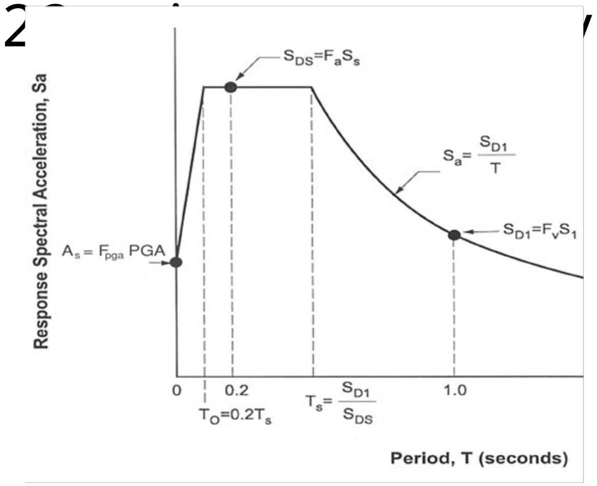

**Appendix C** to the LRFD Seismic Bridge Design Guide Specs
Provides background to RTGM and procedures for development of site-specific RTGM

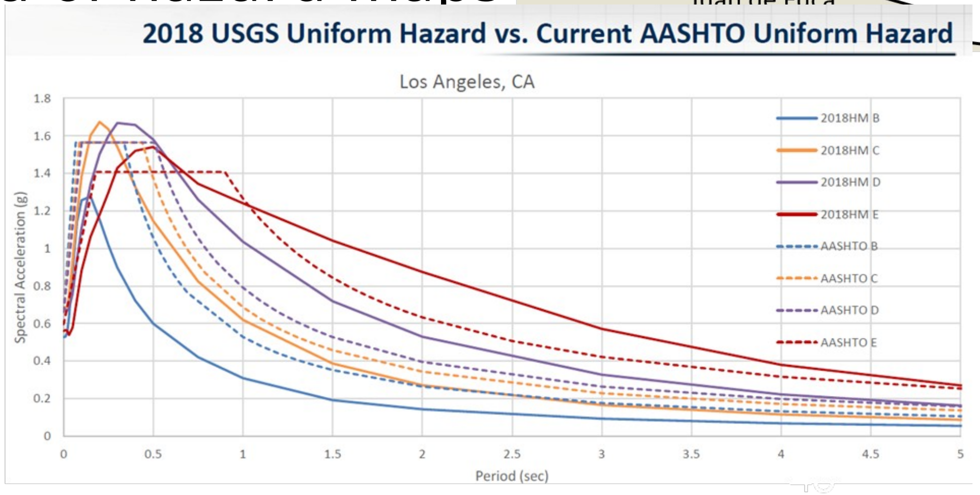
# Changes Affecting Design Procedure

**Changes in USGS Hazard Model**

- Seismic sources/faults
- Next Generation Attenuation relationships
- Soil effects and Site Factors directly in design spectra
- **Basin effects**
- **USGS** online database in lieu of hazard maps
- 2 … s. 0, 0.2,



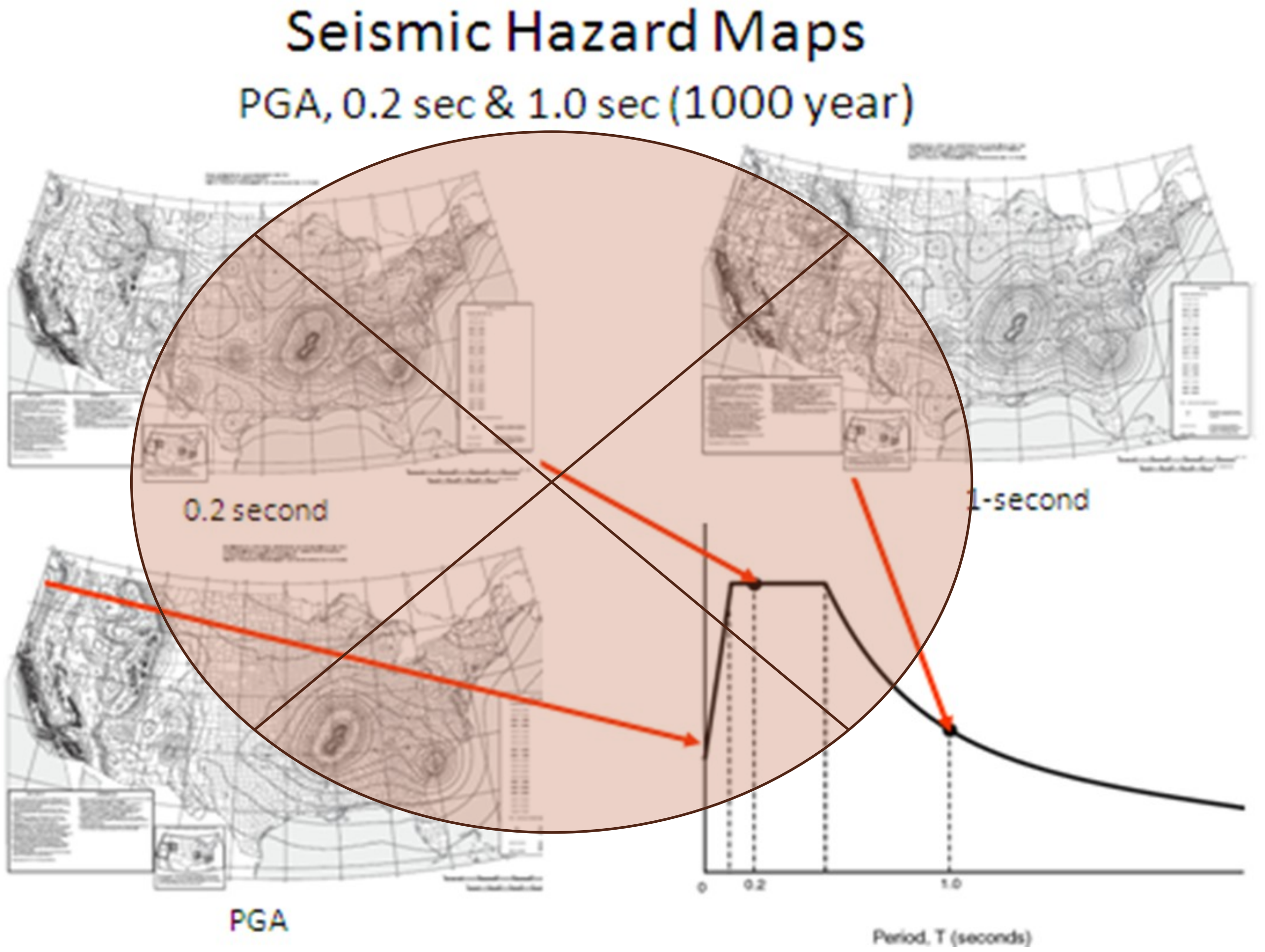



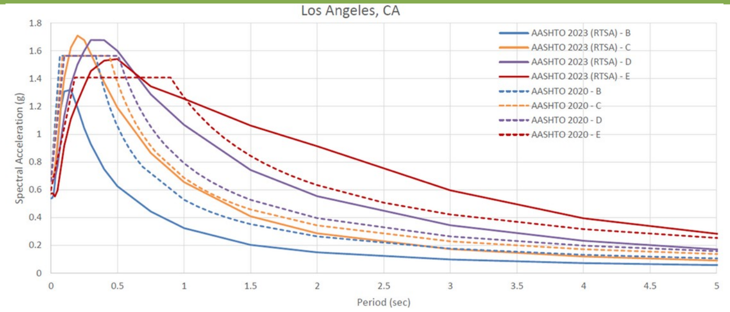



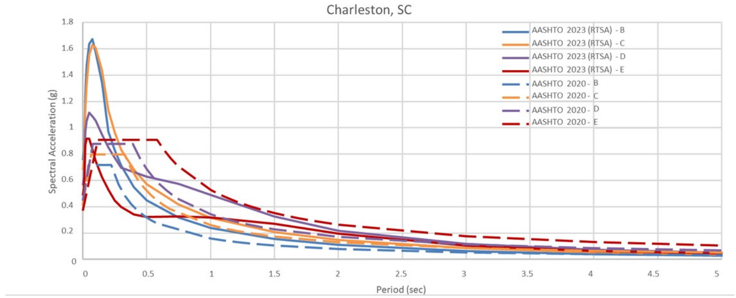
# Changes to AASHTO Seismic Bridge Design

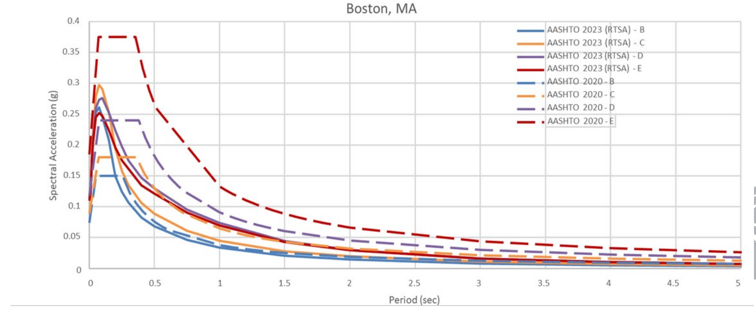
- No maps included - USGS provides Seismic Design Ground Motions. Webtool on USGS website will provide 22-point spectra.
- Develop hazard curve for bridge site **based on probability of occurrence, not exceedance.**
- Method for calculating an equivalent 1-sec spectrum acceleration provided
- Choose target probability of initial collapse, say 1.5% in 75 years.

# Summary of Changes to AASHTO Specifications

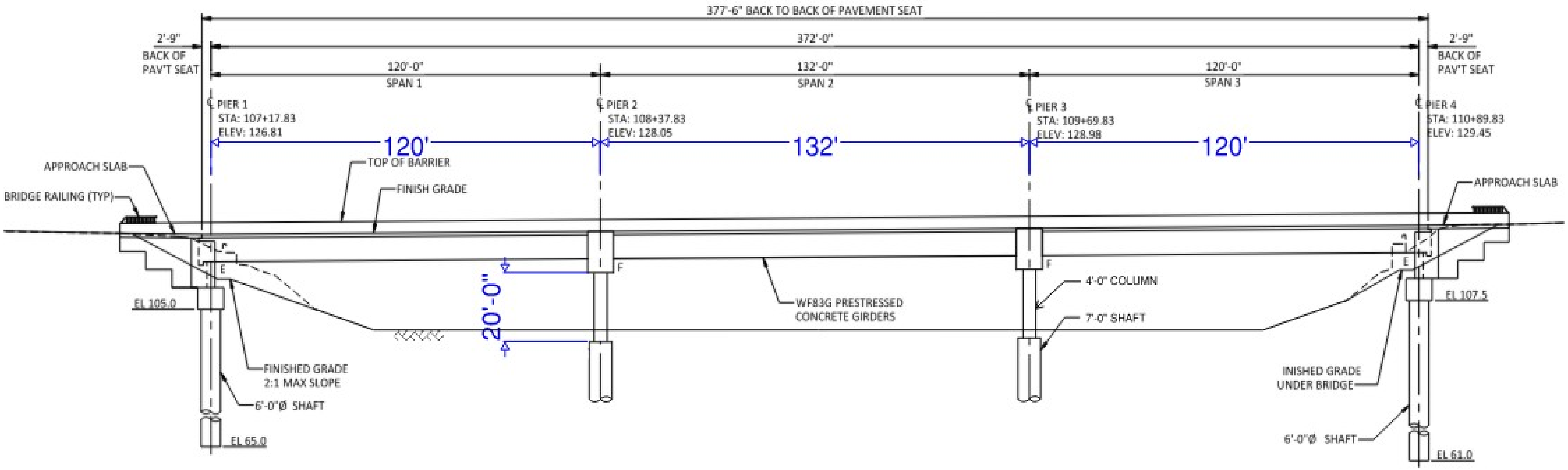


# UHGM and RTGM Design Comparison – WA Case Study



# Key Features

The design was governed mostly by the minimums and shear design.

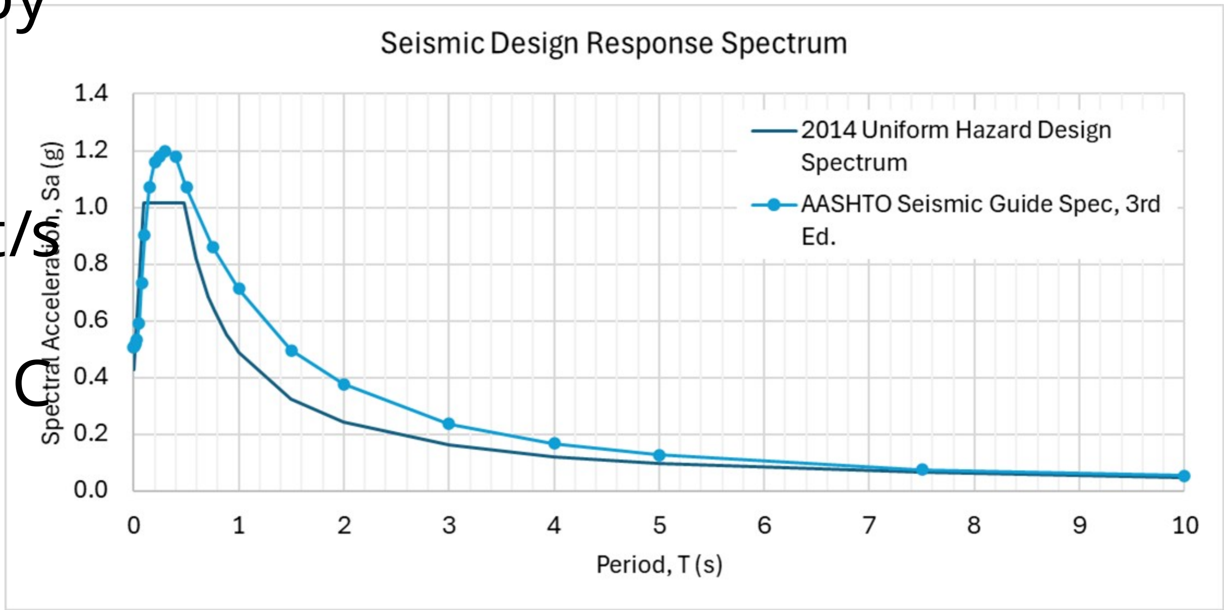
**Seismic Design Parameters:**

Site at the Everett with vs = 900ft/s (measured) site class D.

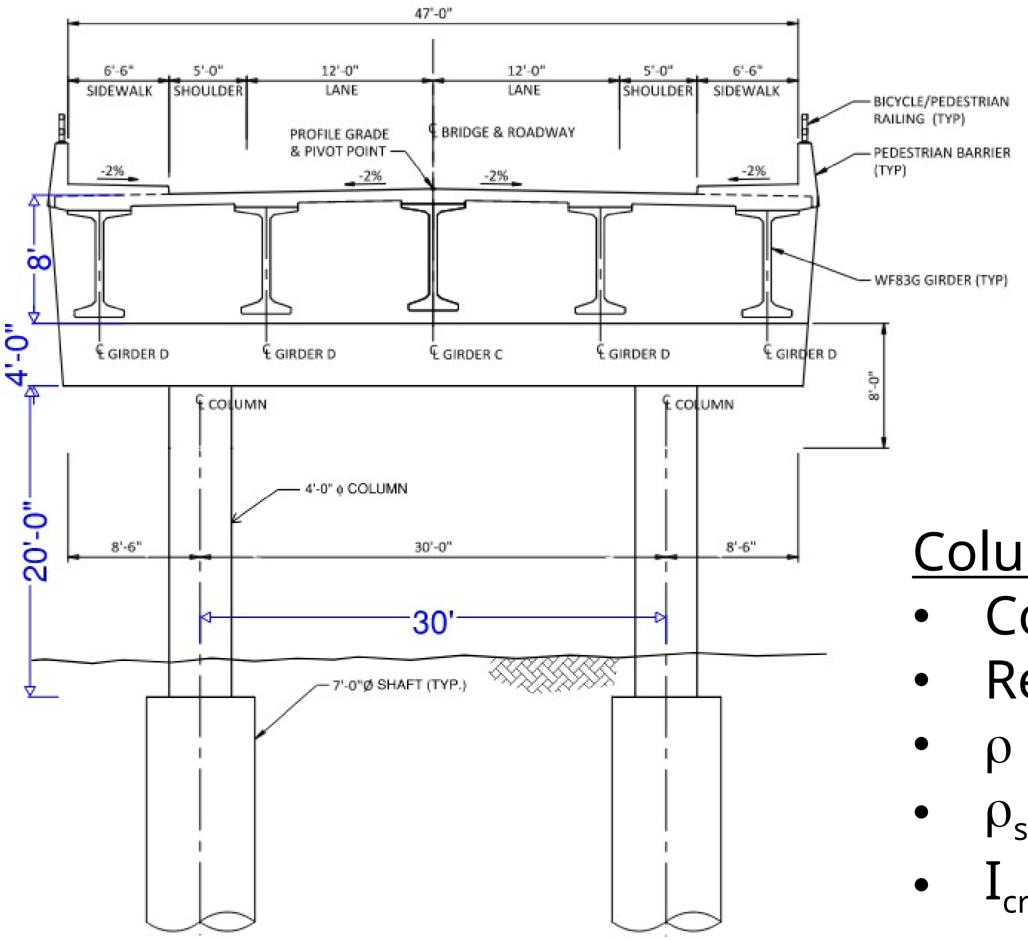
The 2014 Uniform Hazard in SDC C vs the 2023 risk targeted that is SDC D.

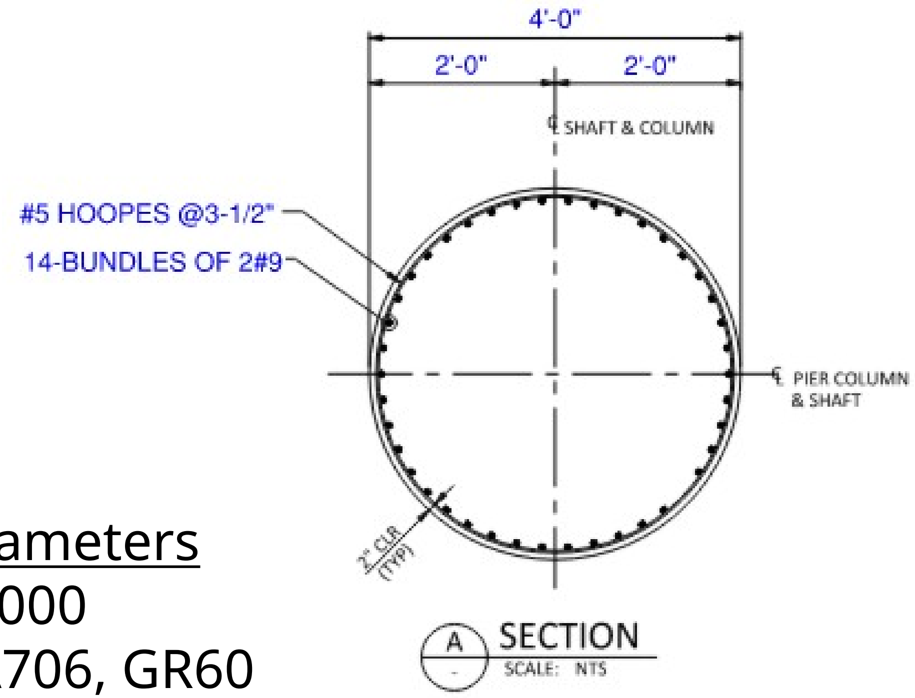
**Three-span** bridge.

Column height 20 ft, diameter = 4 ft, long. Reinf. = 28-#9 (ρs = 1.5%), trans. Reinf. = #5@ 3.5" (ρs = 0.082)



# Substructure Detail




<u>Column Design Parameters</u>

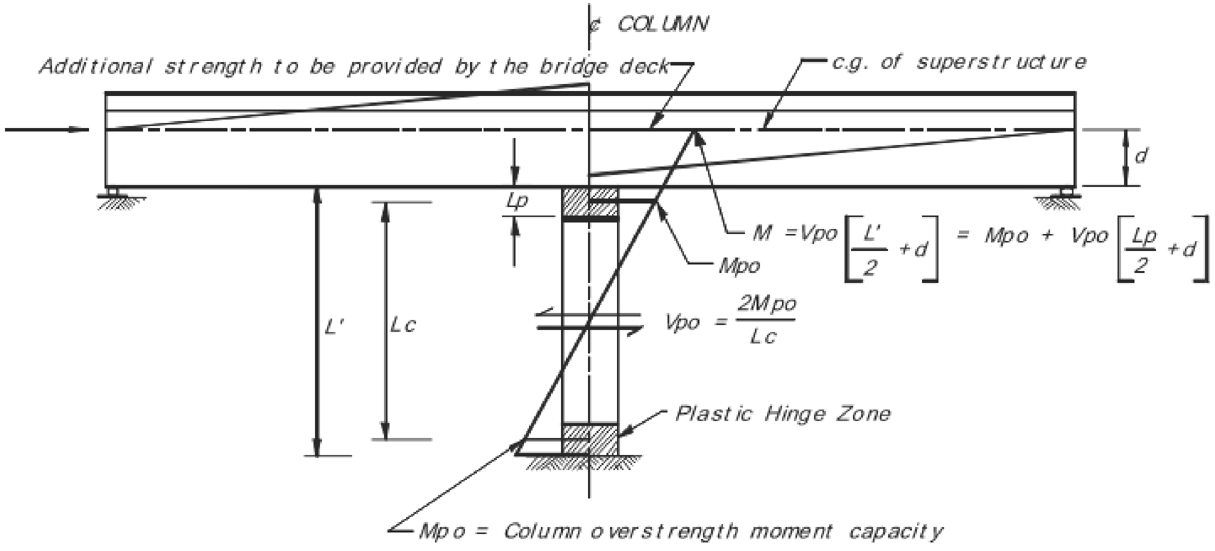
- Concrete Class 4000
- Reinforcement A706, GR60
- $\rho = 0.015$
- $\rho_s = 0.0082$
- $I_{cr}/I_g = 0.473$

# Displacement Capacity

<u>Longitudinal Pushover</u>

- Lc =20 ft, in double curvature

| | |
|---|---|
| $P_o$ (kip) | 1450 |
| $V_{po}$ (kip) | 530 |
| $M_{po}$ (kip.ft) | 5,298 |
| $\Delta_y$ (in) | 1.13 |
| $\Delta_c$ (in) | 5.16 |



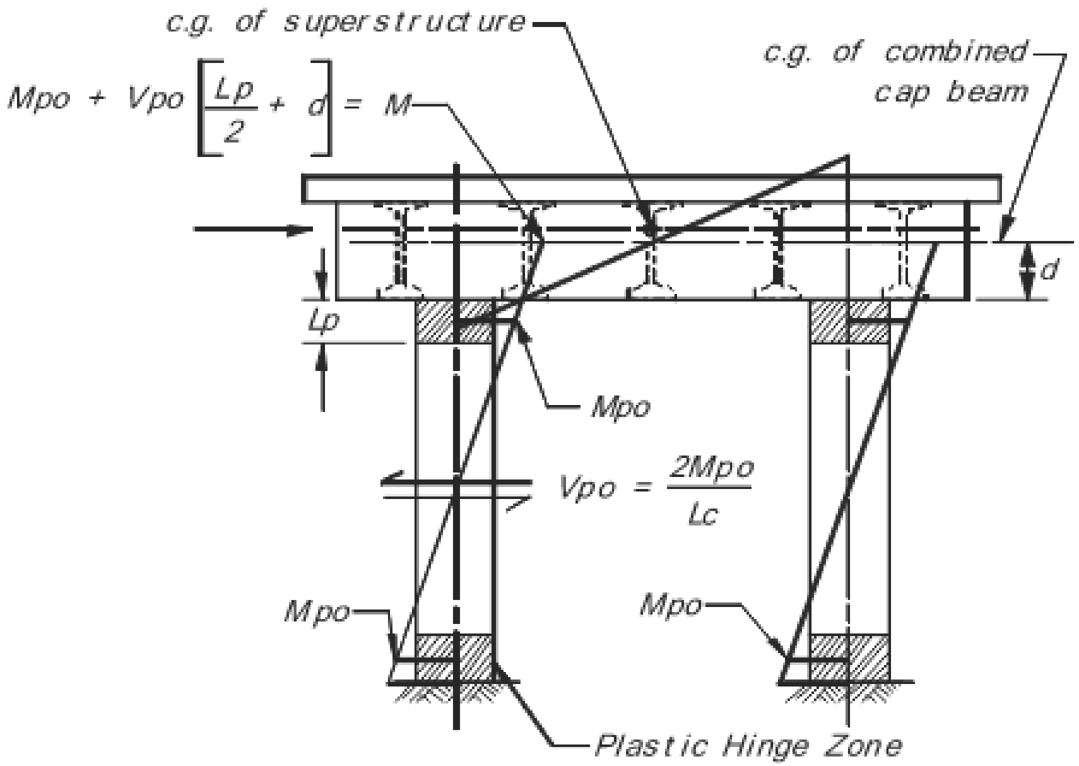

(a) Longitudinal Response for Non-integral Abutments

# Displacement Capacity

<u>Transverse Pushover</u>

- Lc =20 ft, in double curvature

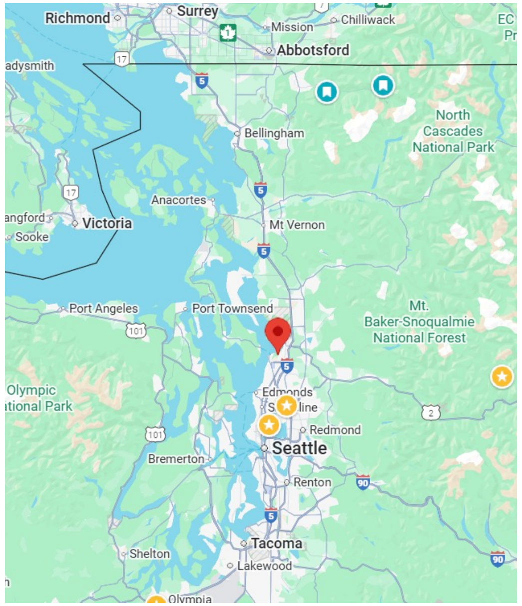
| | $P_{min}$ | $P_{max}$ |
|---|---|---|
| $P_o$ (kip) | 820 | 2080 |
| $V_{po}$ (kip) | 467 | 583 |
| $M_{po}$ (kip.ft) | 4,674 | 5,833 |
| $\Delta_y$ (in) | 1.12 | 1.16 |
| $\Delta$ (in) | 5.86 | 4.56 |




(b) Transverse Response for Dual Column Pier
With Raised Cap Beam - I Girder

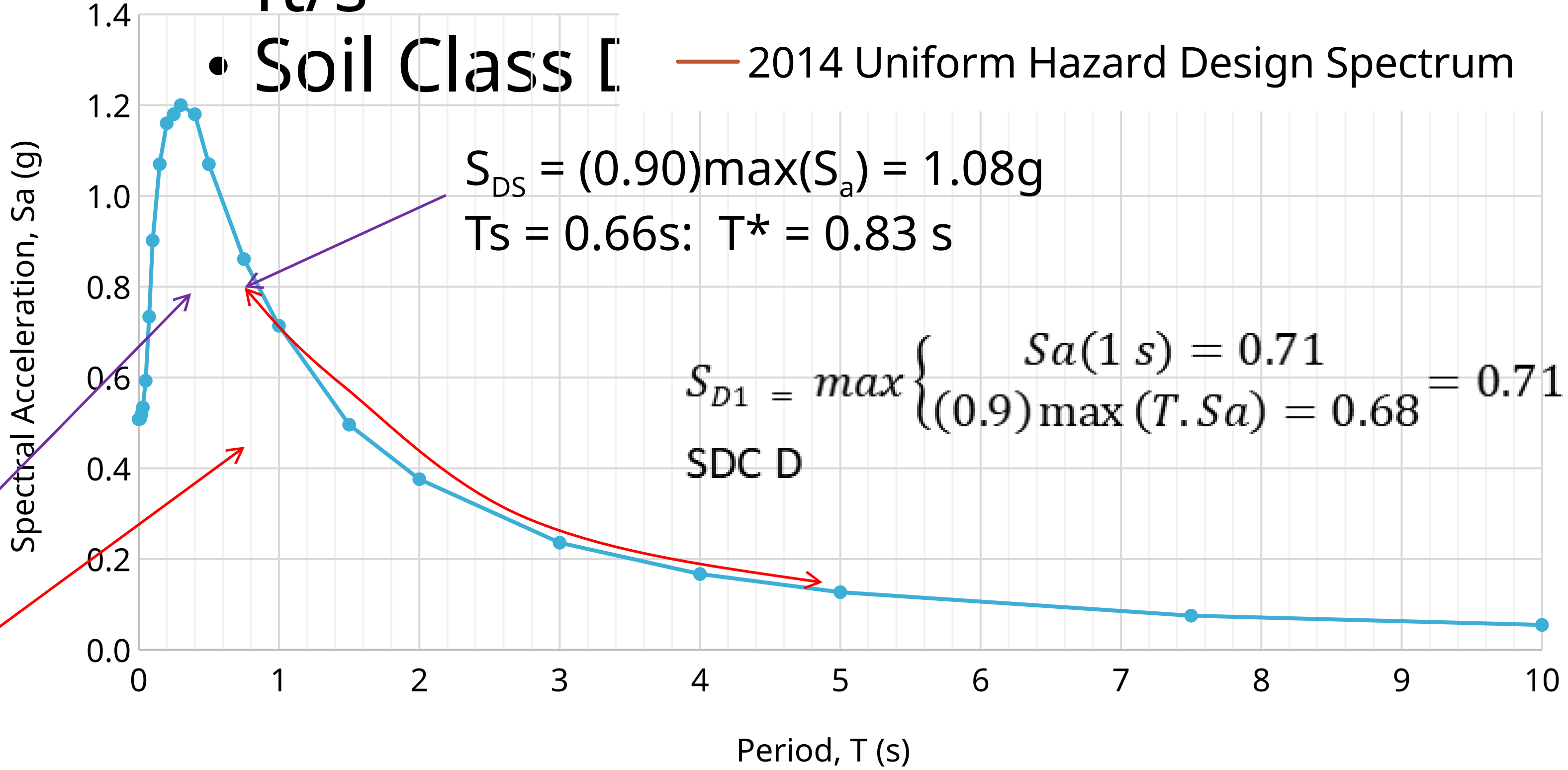
# Design Spectrums

- Measure directly $v_s$ = 900 ft/s
- Soil Class [




Ts = 0.481s: T* = 0.60 s

$S_{D1}$ =0.49g: SDC C




$S_{DS}$ = (0.90)max($S_a$) = 1.08g

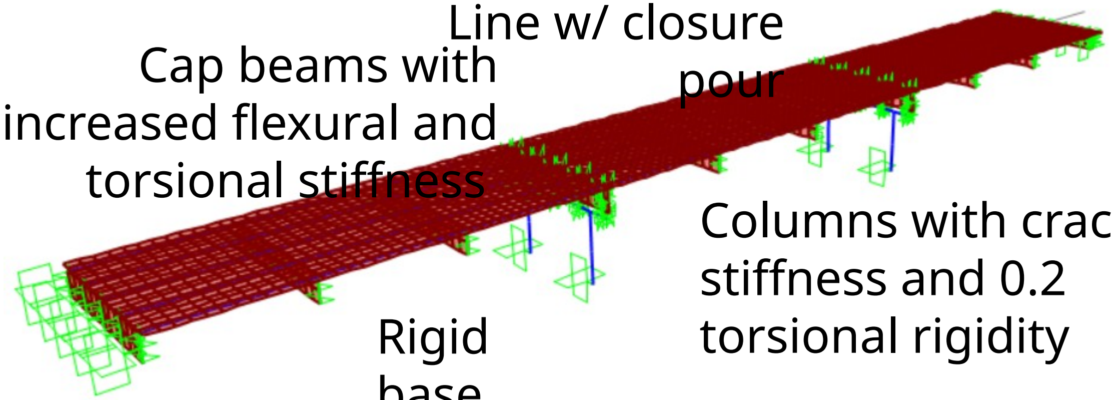
Ts = 0.66s: T* = 0.83 s

$$S_{D1} = max\begin{cases} Sa(1\ s) = 0.71 \\ (0.9)\max(T.Sa) = 0.68 \end{cases} = 0.71$$

SDC D

# Structural Global Model

## CSiBridge BridgeModeler



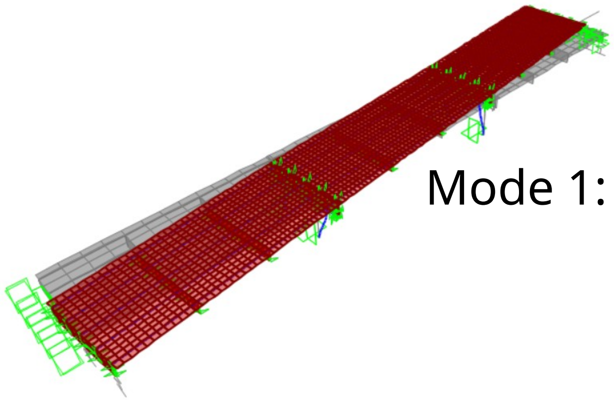
Double Bearing Line w/ closure pour

Cap beams with increased flexural and torsional stiffness

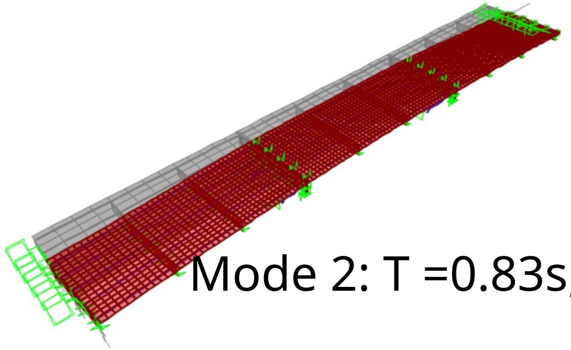
Columns with cracked stiffness and 0.2 torsional rigidity

Rigid base

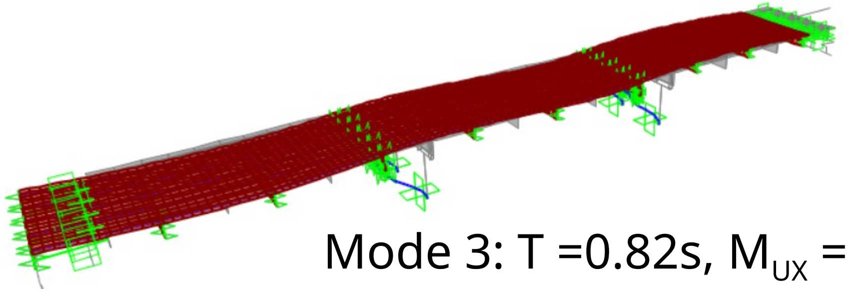
Roller Abutments
No longitudinal and transverse contributions



Mode 1: T =1.26s, $M_{RZ}$ = 0.96



Mode 2: T =0.83s, $M_{UY}$ = 0.95



Mode 3: T =0.82s, $M_{UX}$ = 0.96

# Design Check

| Direction | 2014 UH | 2023 RT | Limit |
|---|---|---|---|
| Longitudinal | | | |
| Displacement (in) | 3.9 | 5.4 | 5.16 |
| Ductility Demands ($\mu_D$) | 3.4 | 4.77 | 6 [1] & 4.0 [2] |
| $P.\Delta/M_p$ | 0.05 | 0.07 | ≤ 0.25 |
| Transverse | | | |
| Displacement (in) | 3.8 | 5.1 | 4.6 |
| Ductility Demands ($\mu_D$) | 3.4 | 4.57 | 6 [1] & 3.9 [2] |
| $P.\Delta/M_p$ | 0.07 | 0.10 | ≤ 0.25 |

[1] Member ductility limit per SGS 4.9.
[2] Member ductility demand for shear capacity.

# Design Update

The 2023 RTGM demands require:

- a larger ductility and shear capacity in the column.
- Increase transverse reinforcement to #6 HOOPS @ 3.5” ($\rho_s$ = 0.0116).
- Larger transverse and longitudinal displacement

# Design Check – Updated Reinforcement

| Direction | 2014 UH | 2023 RT | Limit |
|---|---|---|---|
| <u>Longitudinal</u> | | | |
| Displacement (in) | 3.9 | 5.4 | 6.26 |
| Ductility Demands ($\mu_D$) | 3.4 | 4.64 | 6 [1] & 5.3 [2] |
| $P.\Delta/M_p$ | 0.05 | 0.07 | $\leq 0.25$ |
| <u>Transverse</u> | | | |
| Displacement (in) | 3.8 | 5.1 | 5.6 |
| Ductility Demands ($\mu_D$) | 3.4 | 4.65 | 6 [1] & 4.7 [2] |
| $P.\Delta/M_p$ | 0.07 | 0.10 | $\leq$ |

[1] Member ductility limit per SGS 4.9.
[2] Member ductility demand for shear capacity.

Updated values

# Design Comparison

| Parameter | 2014 UH | 2023 RT |
|---|---|---|
| Column size | 4-ft Dia. | 4-ft Dia. |
| Transverse reinforcement | #5@3.5” | #6@3.5” |
| Displacement Demand | | |
| Longitudinal | 3.39” | 5.4” |
| Transverse | 3.8” | 5.1” |
| Ductility demands | 3.4 | 4.7 |
| Performance Level | Recovery | Ordinary |

Needs Explanation: those bridges designed as recovery using 2014 UHGM meets ordinary using 2023 RTGM

# Design Summary & Conclusions

- Minor budget increase for analysis and geotechnical investigations.
- There are new calculations for the parameters (vs, $S_{D1}$, $S_{DS}$, T*).
- Bridges designed by SGS 2nd Edition may not work with the new RTGM.
- SGS 2nd Edition gives you a Service Level that can be different from the new guide specifications.
- The new spectrum causes an increase in the demands on the columns, and in turn, a reduction in the seismic performance.

*Thank you*