Hazard-Based Risk and Cost-Benefit Assessment of Temporary Bridges in California

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Motivation & Goal

- No general consensus exists on what hazard level should be utilized in the seismic design of **temporary bridges whose service life is ~5 years**

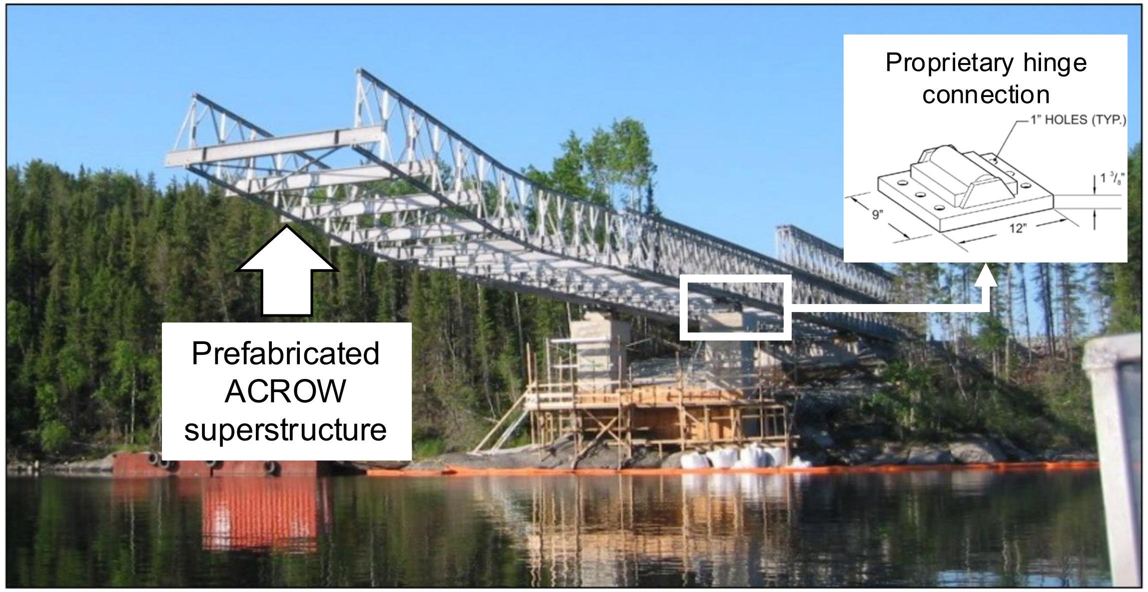
- Current practice for *ordinary bridges* is based on a hazard level of 5% probability of exceedance in 50 years (~975-year return period). Extending this approach to the design of temporary bridges would be overly conservative and not economical

- In 2011, Caltrans issued a memo to designers advocating the use of design spectra based on 10% probability of exceedance in 10 years (~100-year return period)

- However broad consensus on the most appropriate hazard level is yet to be achieved

- This project carried out a systematic set of analyses across a range of hazard levels and locations of different seismicity in California to lay the foundation for the **development of recommendations to achieve economical, performance-based and hazard-consistent design**

Selected Temporary Bridge Typology & Locations in California



Source: ACROW Bridge. Building Bridges. Connecting People. Technical Handbook, 5th edition, 2016

ACROW superstructure (2-span continuous beam):
- ❑ Assigned geometry and inertial properties
- ❑ Assumed to remain linear (w/ distributed mass)

Two-column bent:
- ❑ Reinforced concrete (RC) columns
- ❑ Circular cross-section
- ❑ Nonlinear elements (plastic hinge)

Data Basin. California Department of Transportation (Caltrans) State Highway routes. (Accessed August 2024)

Analysis Approaches

Approach #1: site-specific & hazard-consistent design

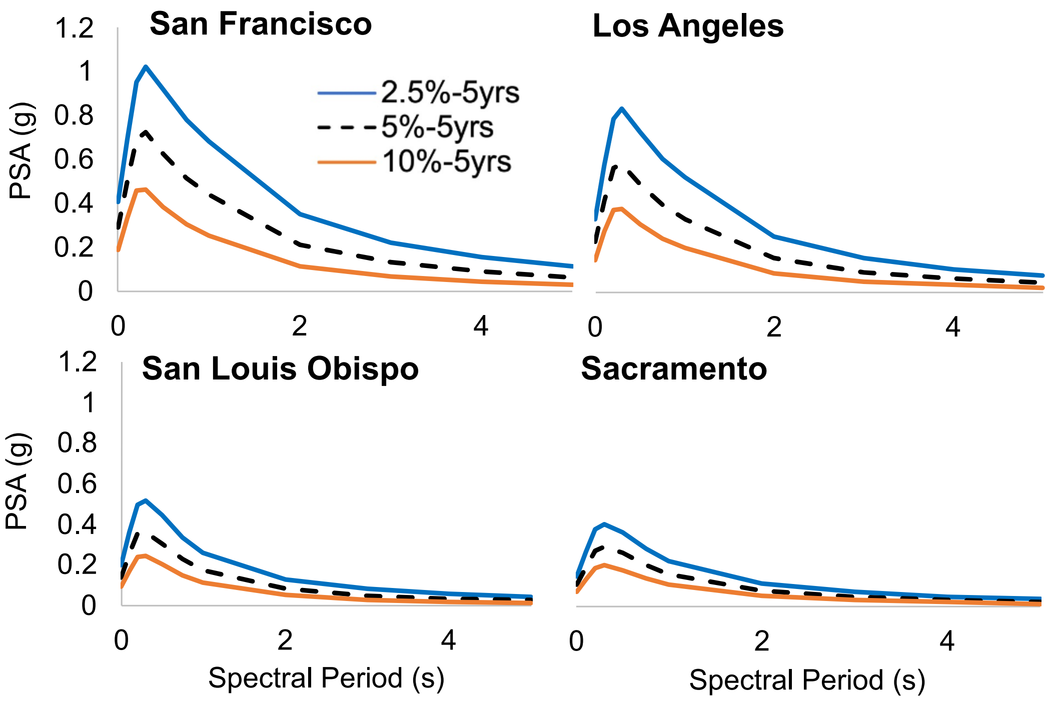
Three hazard levels (HLs) are selected (50, 100 & 200-year return period), temporary bridges are designed for each HL and location, and fragility functions are generated. *Note: The design is performed based on the strength and ductility criteria in the SDC (2019), but minimum design requirements of AASHTO (2020) are not applied.*

Approach #2: baseline bridge model

The bridge designs at the considered locations are updated to meet the *AASHTO* min reinforcement requirements, two additional HLs are investigated (500 & 1,000-year return period) to identify the level of hazard causing the bridge to attain Life-Safety performance.

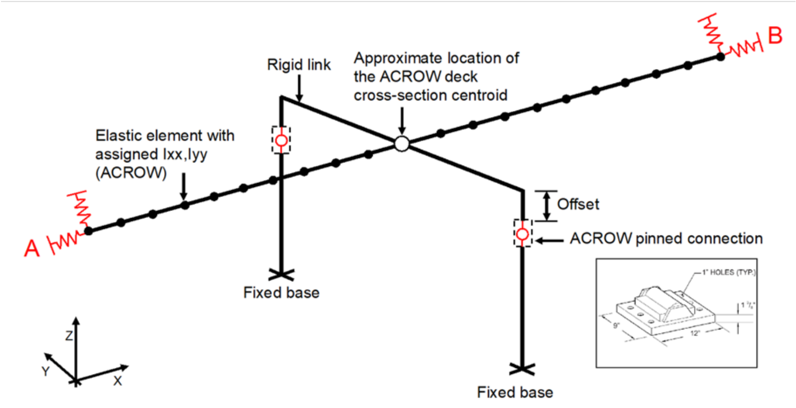
Approach #1

The site-specific & hazard-consistent **bridge design** was carried out based on the columns' displacement ductility, $\mu_D = \Delta_D / \Delta_Y$



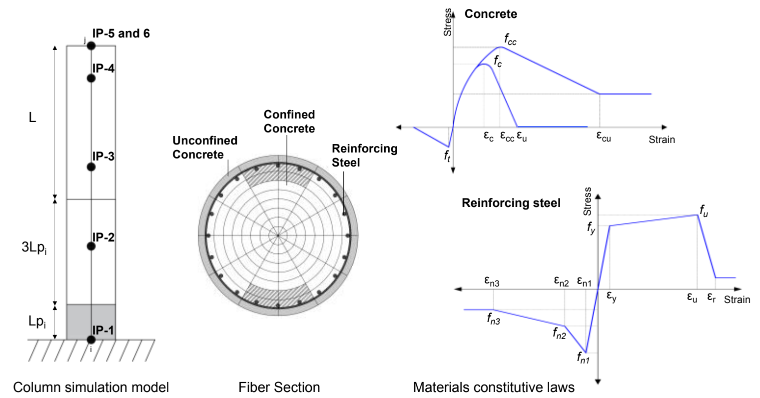
- ❑ Site class D
- ❑ 2018 USGS maps
- ❑ Near-field effects *Campbell- Bozorgnia (2014) and Chiou-Youngs (2014)*

Linear model in CSi Bridge (elastic demand from EDA, Δ_D)



- ❑ The UHS were applied to the bridge in both directions using CQC3
- ❑ The load combination 'Extreme 1' (1D+1EQ) was found to control the design

Nonlinear model in OpenSees (yield displacement, Δ_Y)



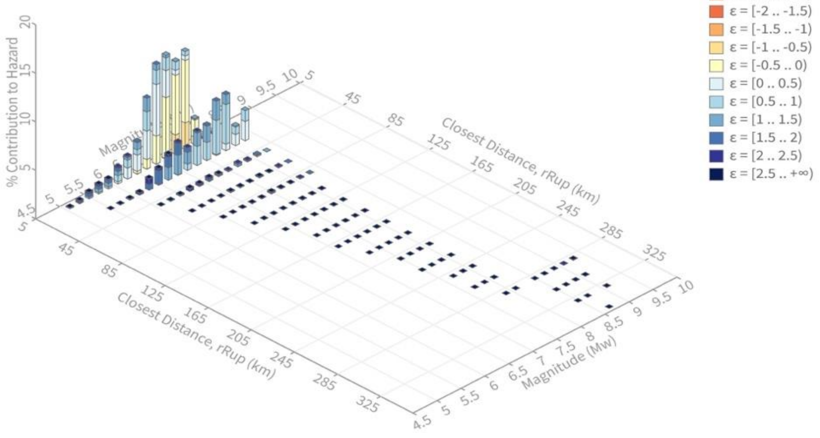
- ❑ Δ_Y was defined as the displacement corresponding to minor concrete cover spalling and the onset of rebar yielding.

Approach #1

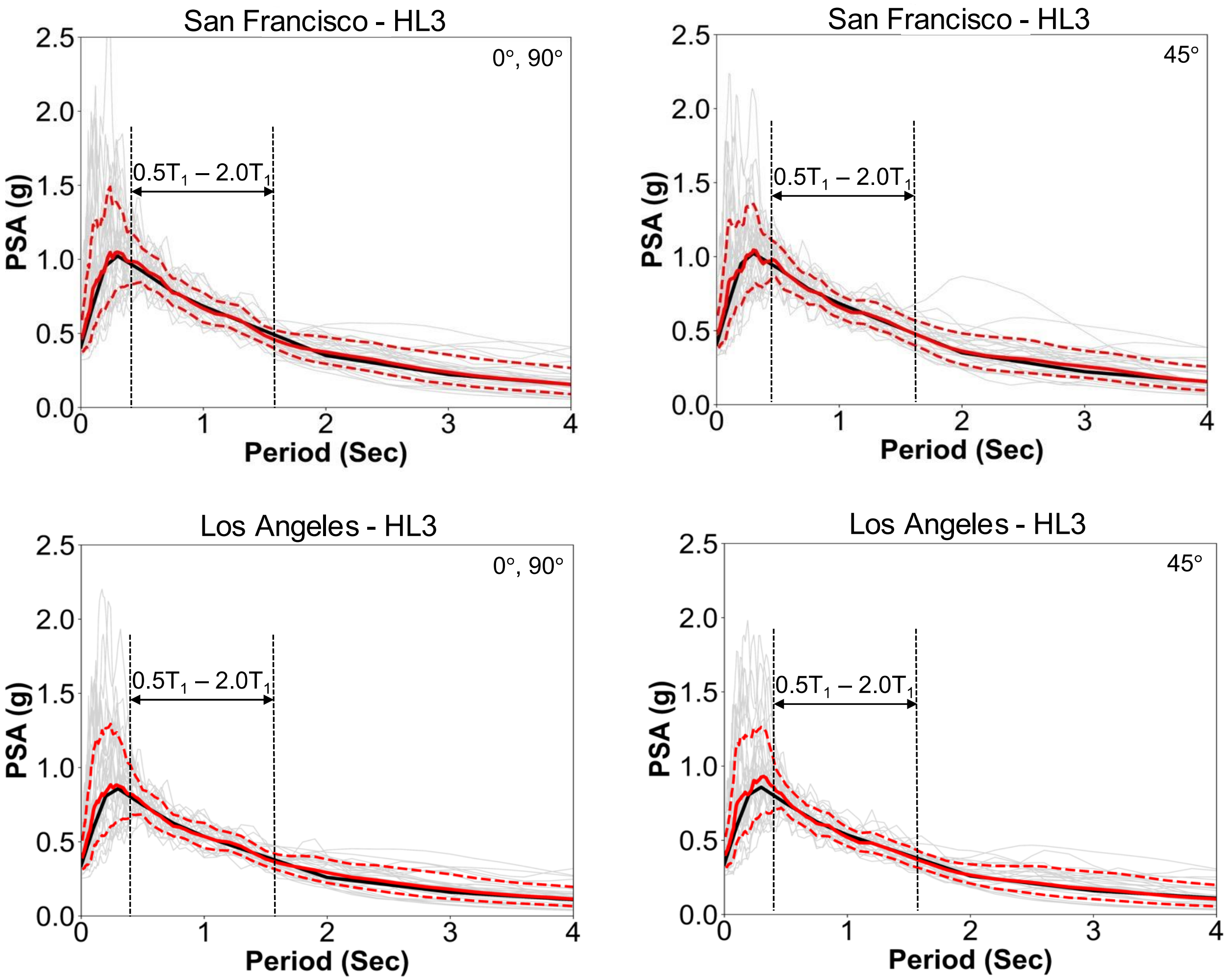
Summary of design data (μ_D < 2)

Location	H (ft)	D (ft)	Longitudinal Reinforcement (#Rebars) [%]			Transverse Reinforcement (#Rebars) [%]		
			HL1	HL2	HL3	HL1	HL2	HL3
San Francisco	24	4	15#9 [0.8%]	20#9 [1.1%]	26#9 [1.4%]	1#4@6 in [0.3%]		
Los Angeles			8#9 [0.4%]	12#9 [0.7%]	20#9 [1.1%]			
San Luis Obispo	18	3	8#7 [0.5%]	10#7 [0.6%]	14#7 [0.8%]	1#3@4.5 in [0.3%]		
Sacramento			6#7 [0.4%]	8#7 [0.5%]	10#7 [0.6%]			

San Francisco



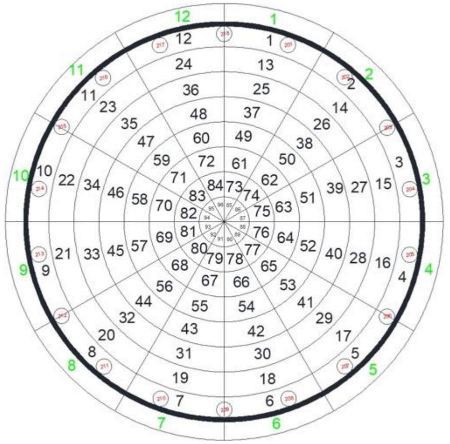
Thirty pairs of ground motions were selected, rotated twice by 45 deg, and scaled <u>for each location and HL</u>

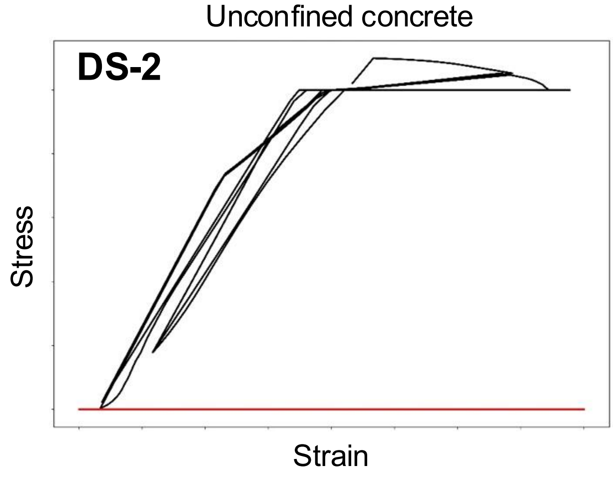


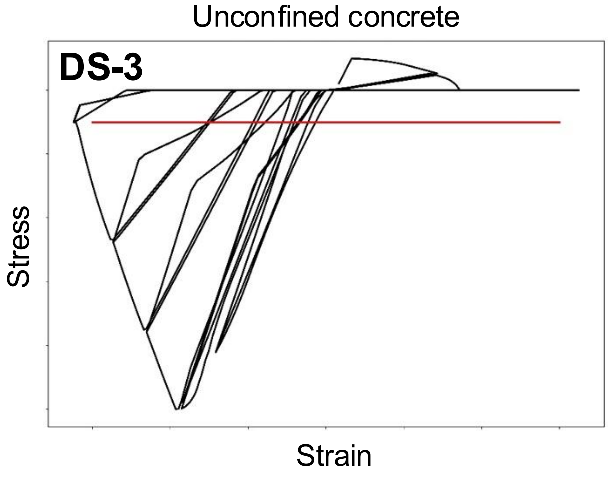
Damage States Definition

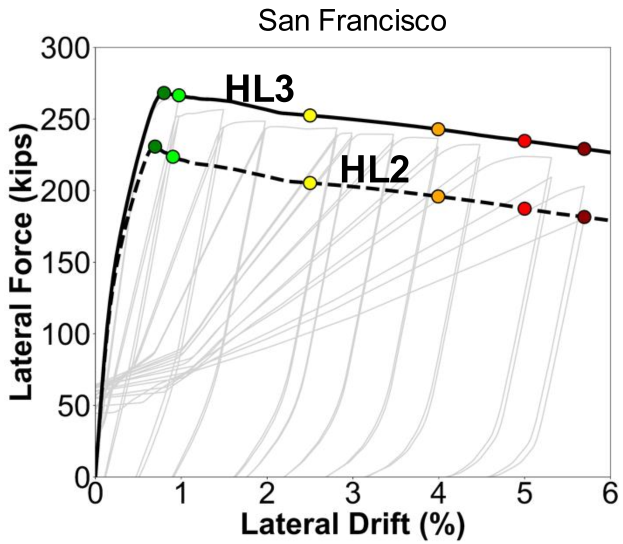
Column Damage State	Definition from Vosooghi and Saiidi (2010)	Criterion
DS-1	Flexural cracking	Zero tensile stress is attained in the concrete cover.
DS-2	Minor concrete cover spalling and shear cracks	The maximum compressive stress of unconfined concrete is attained in the concrete cover ($f_c = f'_c$) and at least one rebar has yielded
DS-3	Extensive flexural cracks and relatively large concrete cover spalling	Zero stress – corresponding to crushing – is attained in the concrete cover.
DS-4	Exposed lateral and longitudinal rebars	The maximum compressive stress is attained in the confined core concrete (f_{cc})
DS-5	Initiation of concrete core damage and initiation of longitudinal rebars bucking.	80% peak stress is attained in the confined core concrete ($0.80f_{cc}$) on the softening branch
DS-6	Loss of axial load bearing due to the extensive rebar buckling and core crushing	Buckling/rupture of at least two longitudinal rebars is attained.

A set of strain and stress-based criteria were introduced based on cyclic pushover analysis

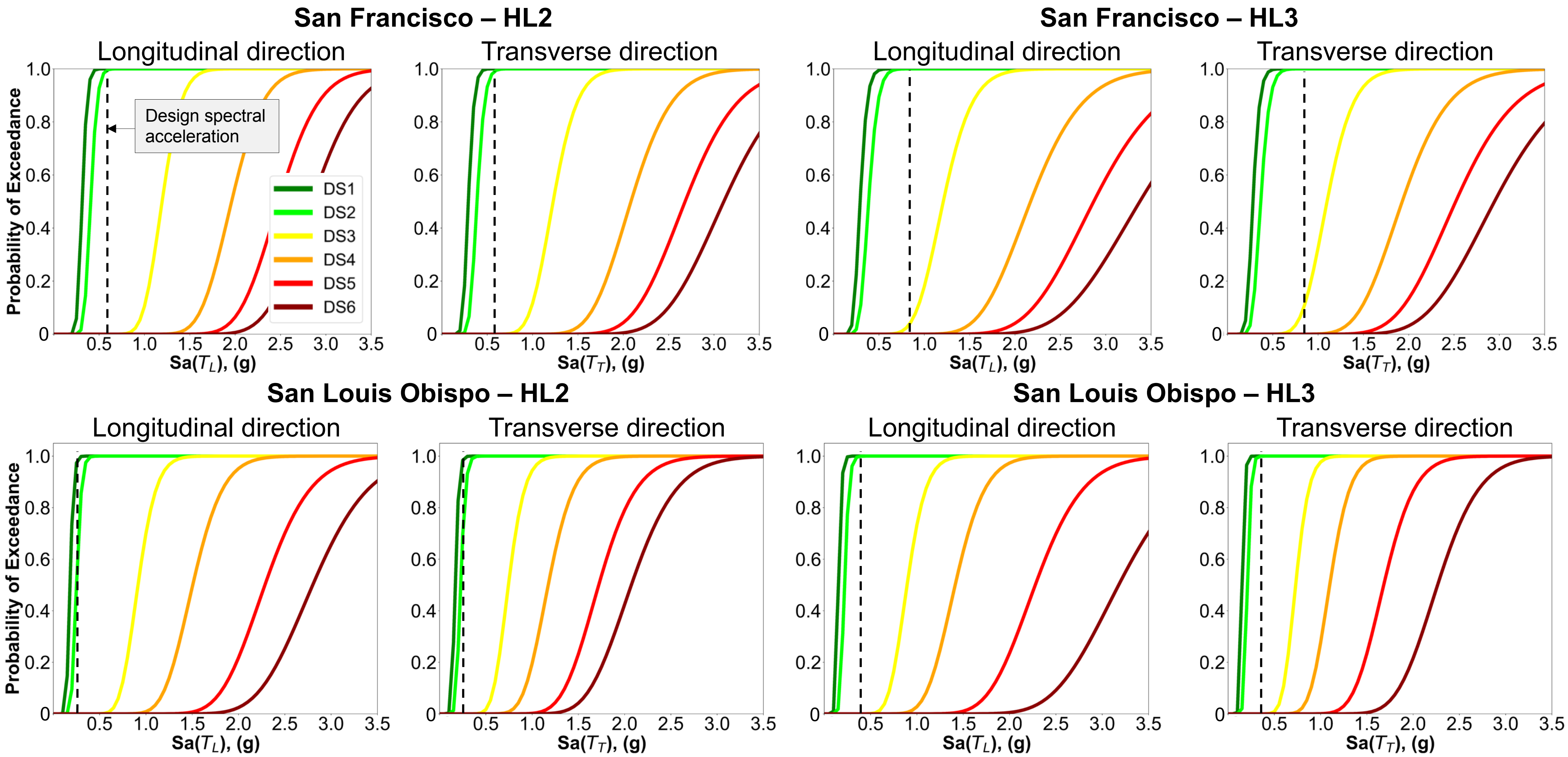








Approach #1

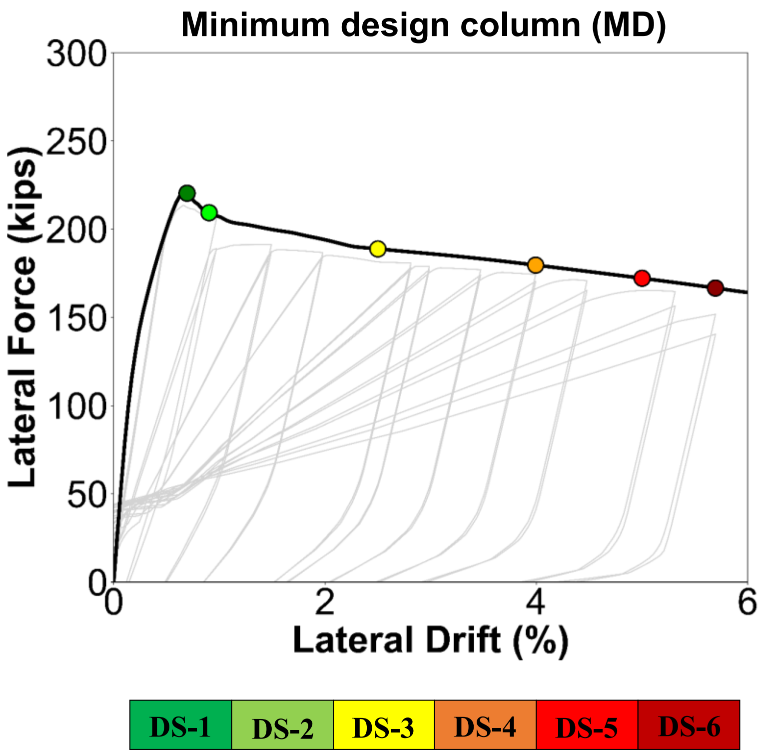


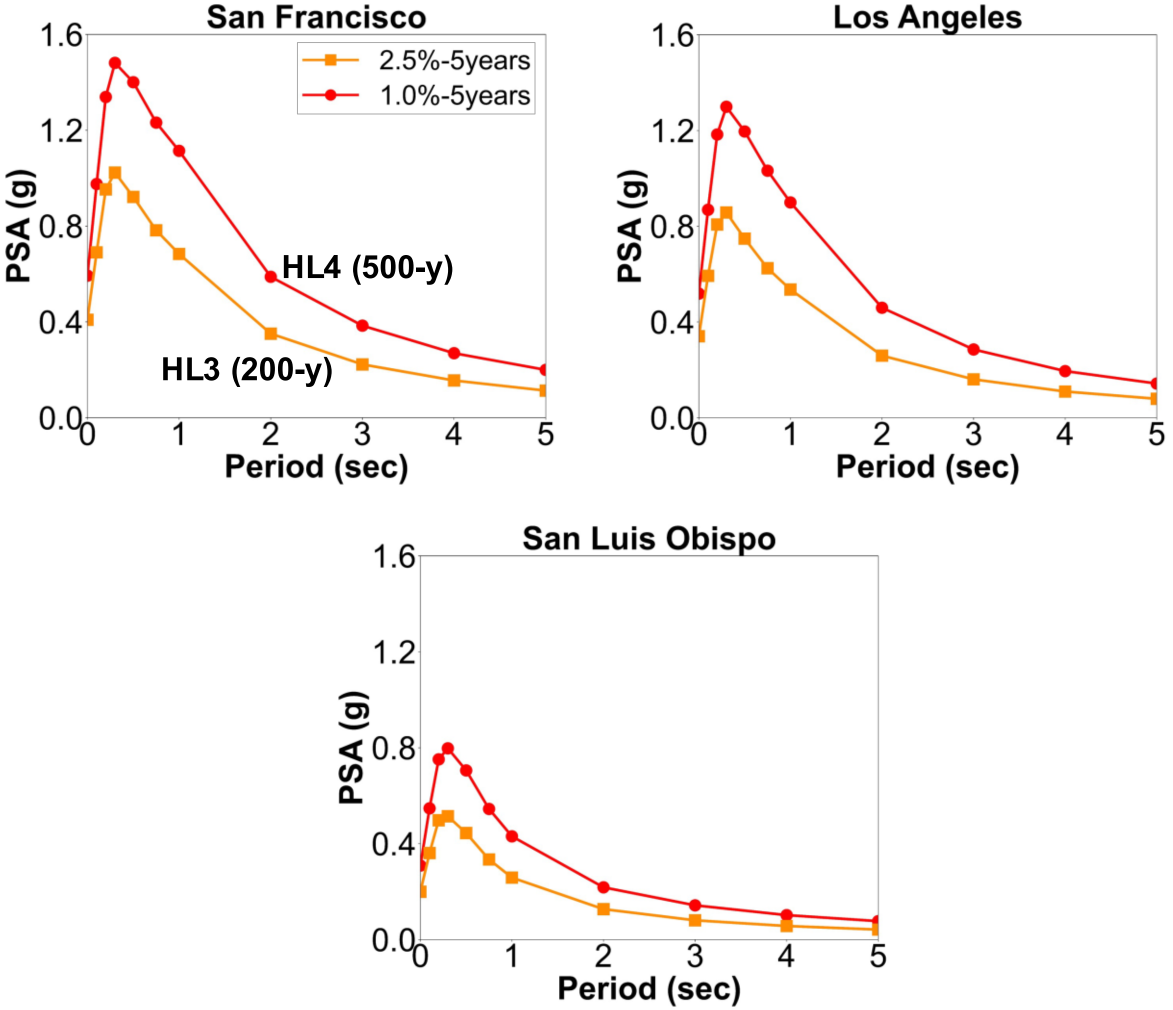
From a performance-based design perspective, this means that if temporary bridges are designed for earthquakes with return periods of 100 or 200 years, demands will not exceed **repairable damage state even when the AASHTO minimum reinforcement requirements are not met.**

Approach #2

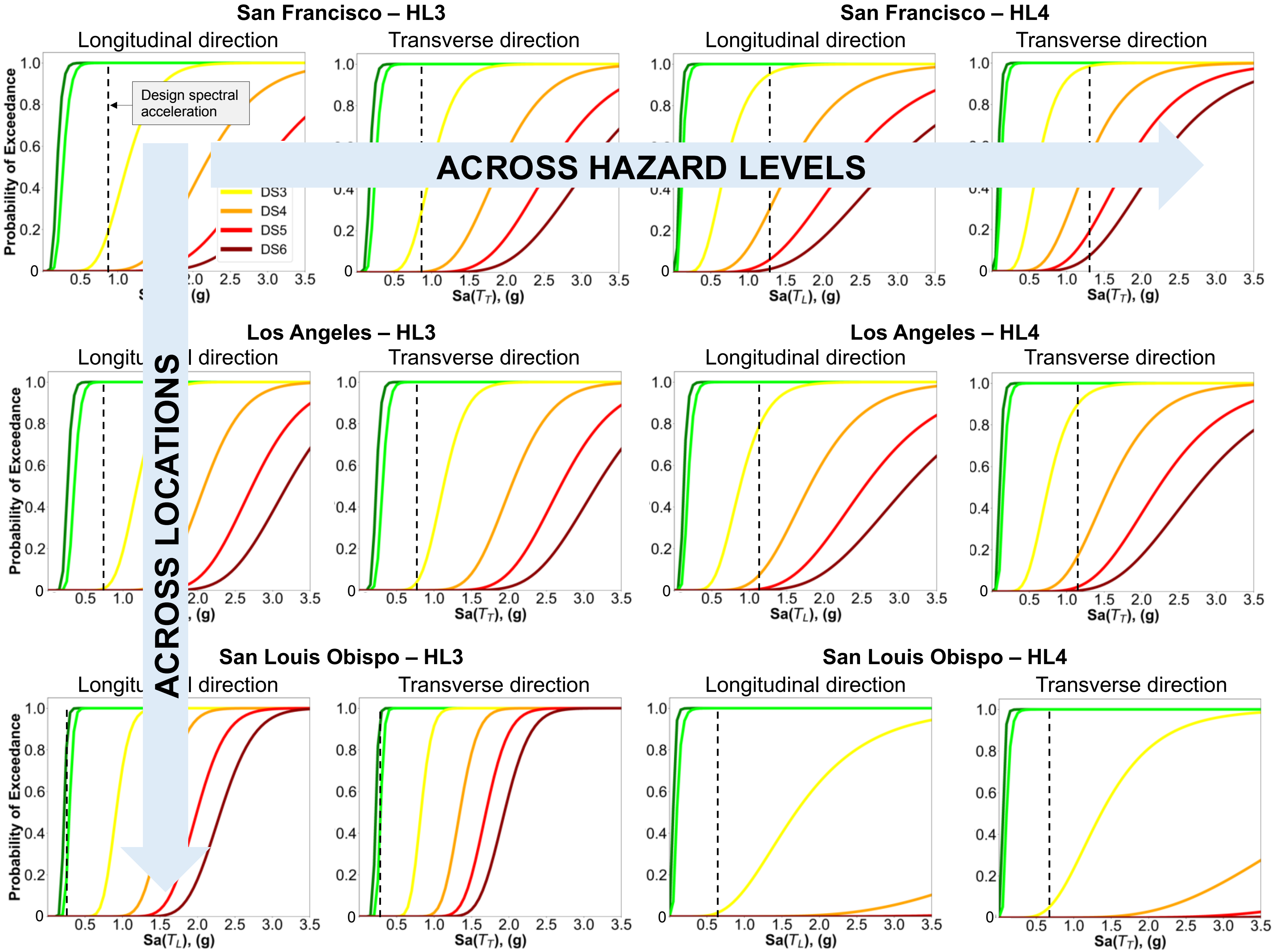
Based on this evidence, this study takes a step forward and attempts to identify the HL for which a **'baseline' temporary bridge designed to strictly meet the AASHTO minimum reinforcement requirements** can ensure Life Safety performance, thus avoiding the need to perform a site-specific analysis.

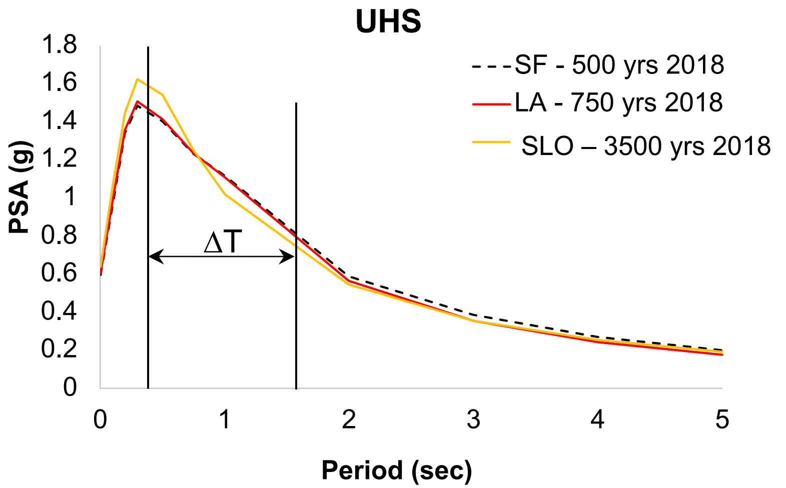
Column height (H)	24 ft
Column diameter (D)	4 ft
Long. reinforcement	**1%**
Transv. reinf. (hinge)	**1#5@ 8in**





Approach #2





To obtain a target performance corresponding to 50% probability of exceeding DS-4 (Exposed lateral and longitudinal rebars) with a baseline MD column, the hazard level needs to be increased to 750 years for LA and to 3,500 years for SLO.

Approach #1 vs Approach #2

Results from Approach#1 demonstrated that if a hazard-consistent design for temporary bridges across locations of different seismicity is targeted (e.g., 100-year return period), **the current design requirements for ordinary bridges must be relaxed.**

Results from Approach#2 demonstrated that if the current minimum design requirements are extended to temporary bridges, **hazard-inconsistent designs would be obtained, particularly at sites of low-to-moderate seismicity**.

Concluding remarks

Objective

Provide the basis for the development of recommendations to achieve economical, performance-based and hazard-consistent design for temporary bridges.

There is a need for developing ***minimum design requirements*** specific to bridges employing lightweight superstructures and with a service life of 5 years, for which ***concrete creep*** controlling current minimum reinforcement ratios is expected to be mitigated (Ziehl et al., 1998; Kim and Gong, 2018).

A satisfactory performance (DS-2) can be achieved for HL up to 200-y return period when ***design minimum requirements for ordinary bridges are relaxed***

The ***methods currently proposed in the literature to obtain reduced spectral amplitudes*** can lead to overestimates of the spectral accelerations up to a factor of ~2.4 when using AASHTO-compliant design spectra