# 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

- Assigning a hazard level of 5% in 50 years (~975 years, per Caltrans SDC 2.0, 2019) to the design of temporary bridges, whose maximum life span is ~ 5 years, 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 years)

- A systematic study examining the performance and expected damage of temporary bridges designed for a range of hazard levels (50 – 200 years) at different sites in California is needed to establish reliable guidelines for the design of such bridges

# Project Objectives

- Assess current Caltrans procedure for temporary bridge design
- Develop a performance/cost matrix displaying the performance level, and corresponding cost-benefit ratios of different bridge models designed for different hazard levels
- Propose recommendations for the design of temporary bridges:
  - What is the appropriate hazard level (return period) for the design of temporary bridges corresponding to 2 critical damage states (repairable and no-collapse)?

# Project Tasks

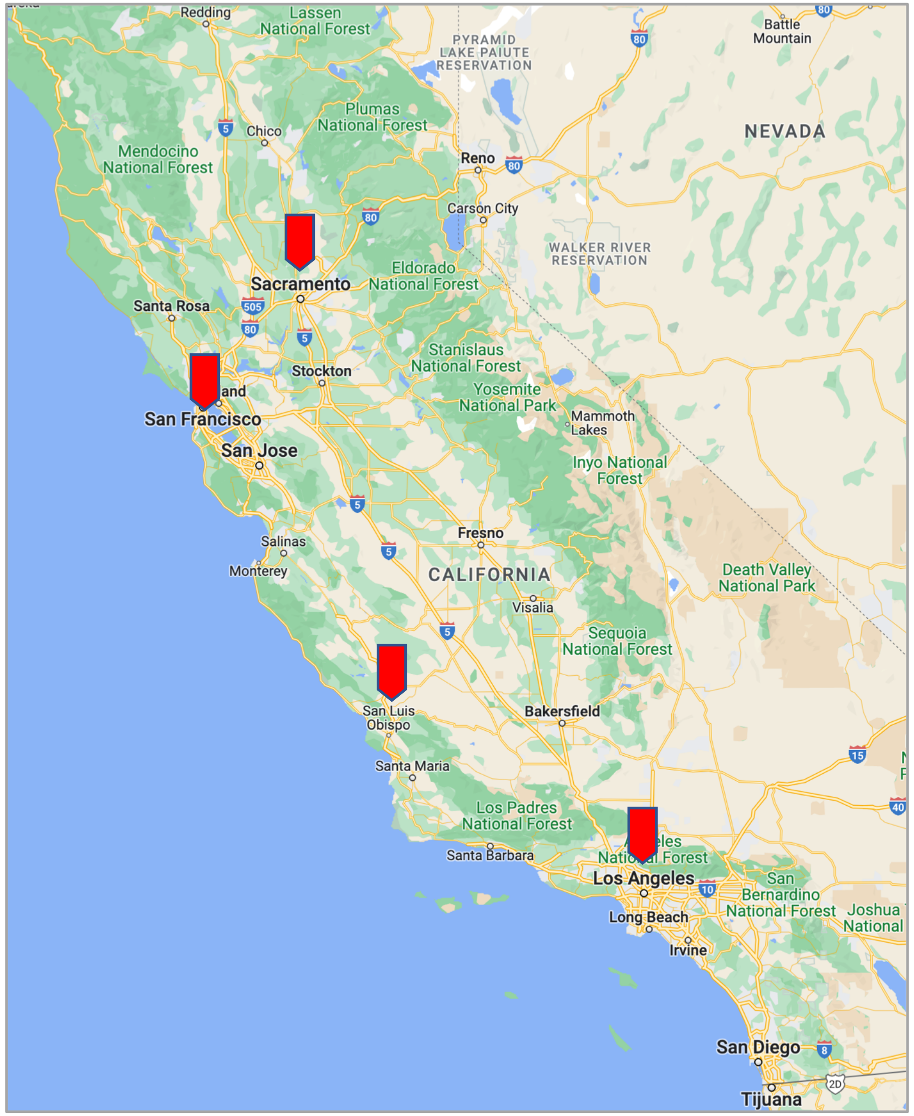
- **Task 1:** Creation of a library of numerical models of typical temporary bridge structures in OpenSees (4 baseline models and 8 variants for 2 alternate hazard levels – total of 12 models)

- **Task 2:** Selection of ground motions followed by evaluation of the seismic performance of the baseline bridge models and their variants through nonlinear time-history analyses

- **Task 3:** Perform bridge life-cycle cost analysis (BLCCA) for each model to facilitate project recommendations as well as Caltrans design and management decisions

- **Task 4:** Development of a performance/cost matrix for each bridge variant and hazard level and recommendation of hazard level for design of temporary bridges

# Task 1-A & 1B



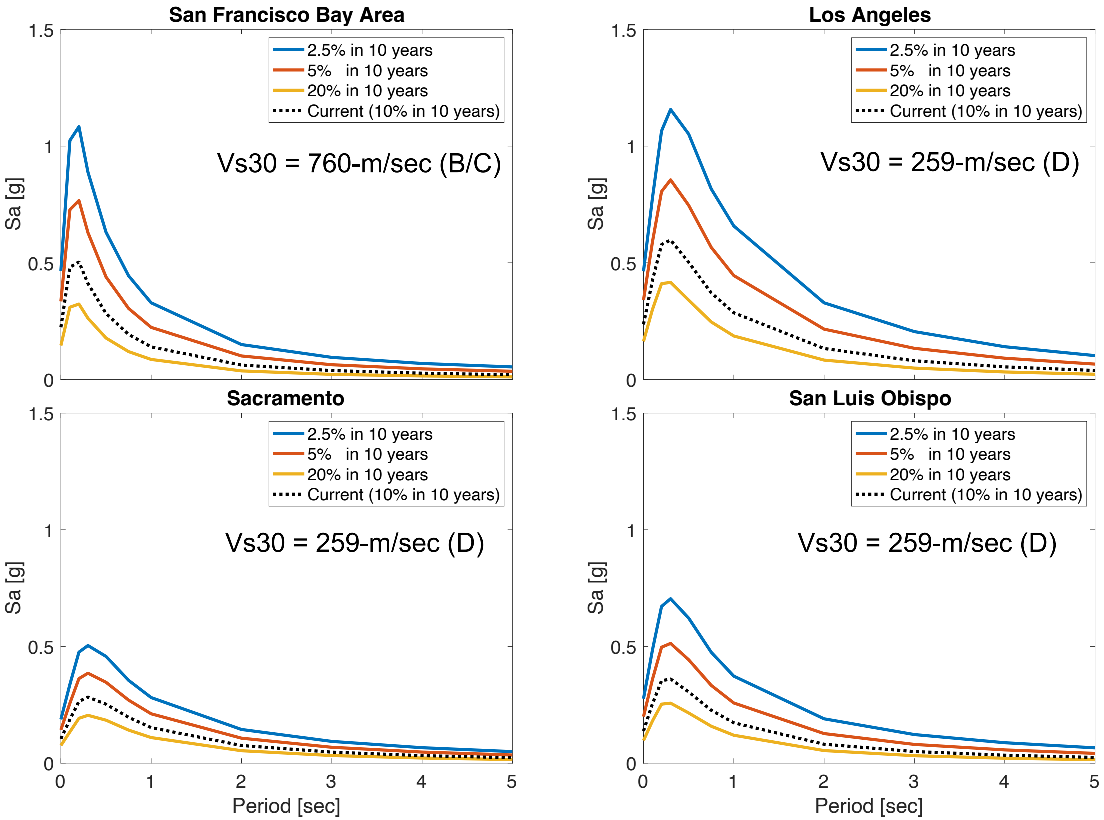

**Subtask 1-A**: A set of 4 bridges representative of the bridge inventory in 4 locations in CA will be designed in consultation with Caltrans engineers:

Locations:

*Moderate seismicity* – Sacramento & San Luis Obispo

*High seismicity* – San Francisco & Los Angeles

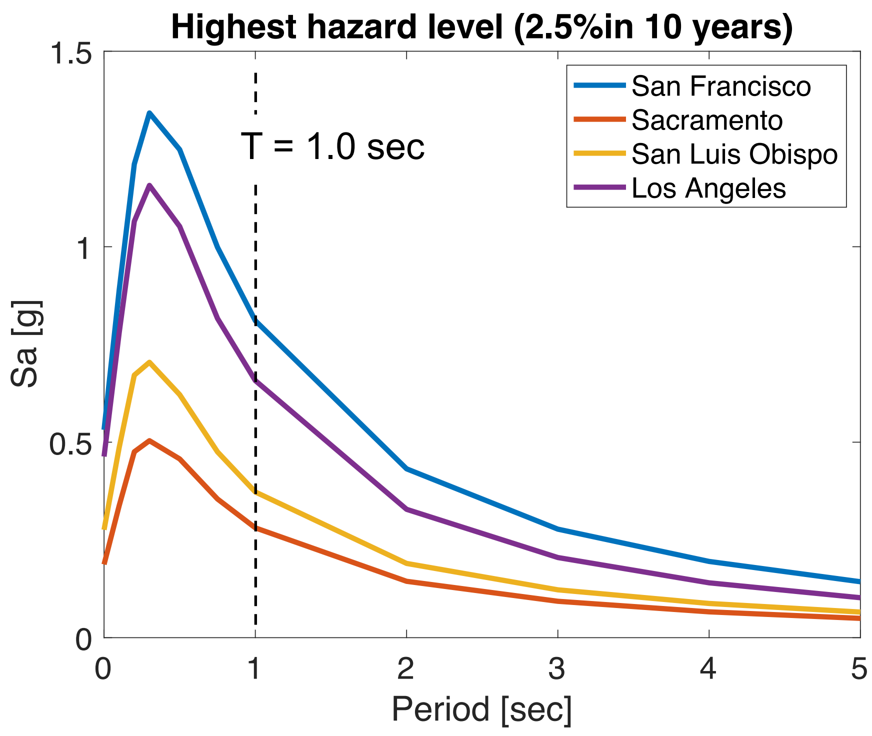
**Subtask 1-B**: Consideration of additional hazard levels to better characterize design requirements at each site



# Task 1-C

**Subtask 1-C:** For each of the 4 bridge typologies identified in subtask 1-A, two model variants will be designed following the procedure below:

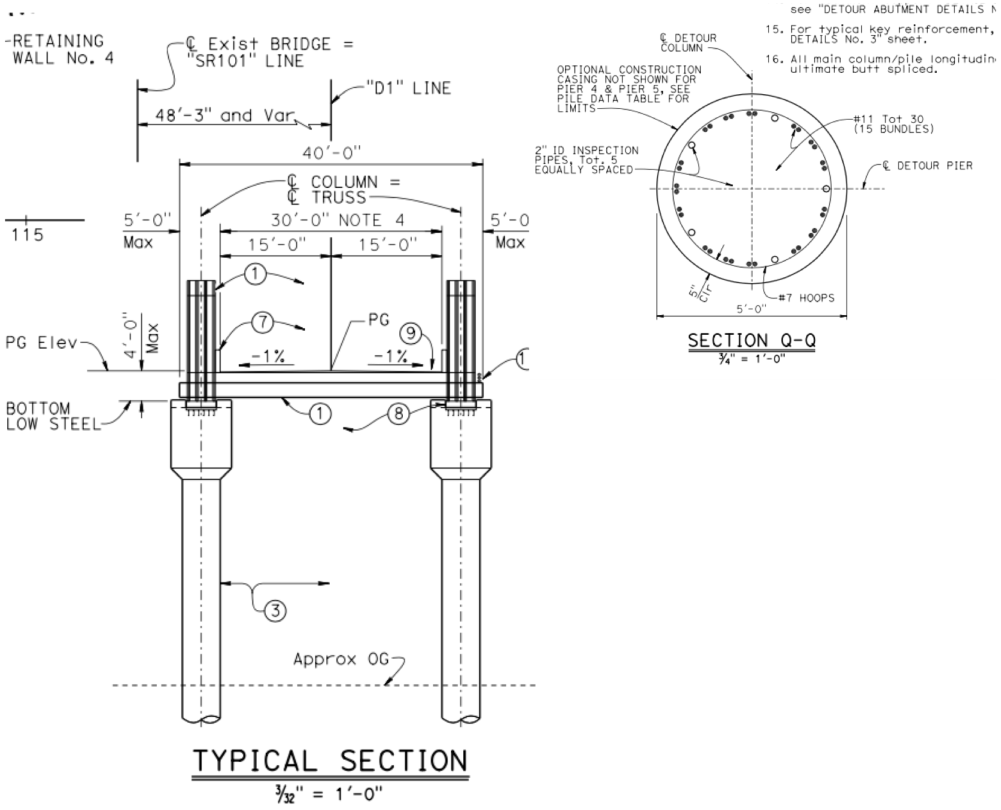
1) Select target period (T = 1.0 sec) for one hazard level (starting from the highest hazard level)
2) Determine Sa(T1) for all sites
3) Select baseline column and cross-section at the site with highest seismicity
4) Conduct pushover analysis to establish capacity and ductility
5) Develop designs (changing reinf. ratio and/or cross-section) for other sites/hazard levels based on spectral values
6) Check other Caltrans design requirements such as ductility, min/max reinforcement, etc.



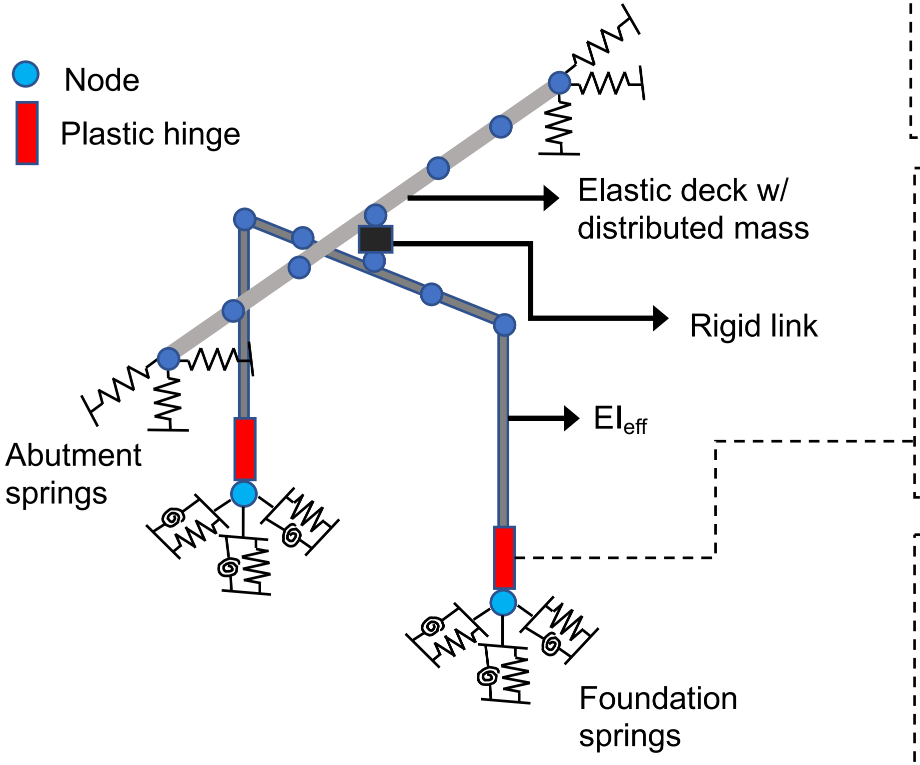
# Task 1-D

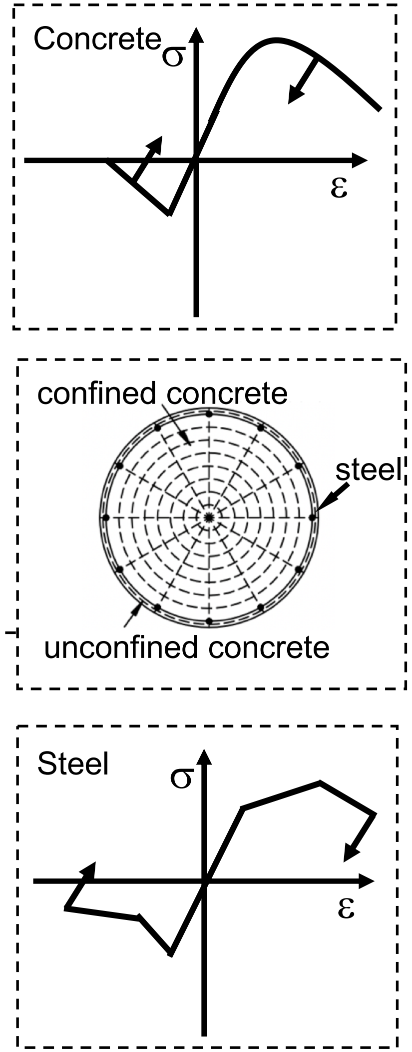
**Subtask 1-D**: 3-D models of each bridge structure (total of 12) will be developed in OpenSees

## Baseline structure/model




## OpenSees Modeling



# Task 2

**Subtask 2-A**: (at least) 11 motions will be selected and scaled to perform NLTHA.

**Subtask 2-B**: NLTH simulations of the bridge models created in subtask 1-D will be carried out in OpenSees. All three components of the ground motions identified in subtask 2-A will be applied. The vertical motions will be scaled at the vertical period of vibration of the bridge.

**Subtask 2-C**: analytical fragility functions for each bridge location will be derived from the results of the NLTHA in subtask 2-B. Displacement-based criteria consistent with recently developed strain-based criteria will be identified for the definition of 2 damage states (repairable and near-collapse)

**Subtask 2-D**: The annual rate of attaining 2 damage states (repairable and near-collapse) will be evaluated.

| Damage state | Damage description | | Damage Index |
|---|---|---|---|
| DS-1 | Cracking of cover | Slight | < 0.1 |
| DS-2 | Minor Spalling | Moderate | 0.10 – 0.20 |
| DS-3 | Major Spalling | | 0.20 – 0.35 |
| DS-4 | Bar buckling | Extensive | 0.35 – 0.65 |
| DS-5 | Exposed core / first-bar rupture | | 0.65 – 0.80 |
| DS-6 | Multi-bar rupture | Complete | 0.80 – 1.00 |
| DS-7 | Column collapse | | > 1.0 |

(from Zhou and Kunnath, 2021)

# Task 3 & Task 4

**Task 3:** a cost analysis and a bridge life-cycle cost analysis (BLCCA) will be performed. Results of this analysis will support Caltrans design and management decisions, accounting for the hazard levels and corresponding costs relative to potential damage.

**Task 4:** a performance/cost matrix displaying the performance level, and corresponding cost-benefit ratios of different bridge models designed for different hazard levels will be generated. The final set of parameters of the matrix will be determined based on the findings of the study.