Aftershock Seismic Vulnerability and Time-dependent Risk Assessment of Bridges

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Motivation

- Caltrans uses the following table to relate bridge seismic damage to post-earthquake functionality and repair priorities

Bridge system damage states	BSST-0 MINOR	BSST-1 MODERATE	BSST-2 EXTENSIVE	BSST-4 COMPLETE
ShakeCast Inspection Priority levels	Low	Medium	Medium-High	High
Likely Immediate Post-Event Traffic State	Open to normal public traffic – No Restrictions	Open to Limited public traffic – speed/weight/lane restrictions	Emergency vehicles only – speed/weight/lane restrictions	Closed (until shored/braced) – potential for collapse
Traffic Operation Implications Is closure/detour needed? Are traffic restrictions needed?	 Very unlikely Unlikely	 Unlikely Likely	 Likely Very Likely	 Very likely Very Likely - Detour
Emergency Repair Implications Is shoring/bracing needed? Is roadway leveling needed?	 Very unlikely Unlikely	 Unlikely Likely	 Likely Very Likely	 Very likely Very Likely - Detour
Component Damage Range Primary components Secondary components	 CDT-0 to 1 CDT-0	 CDT-1 to 2 CDT-1	 CDT-2 to 3 NA	 Above CDT-3 NA

Mangalathu, S., Jeon J-S., Padgett, J. E., DesRoches, R., "ANCOVA-based Grouping of Bridge Classes for Seismic Fragility Assessment", *Engineering Structures*, Vol. 123, 2016, pp 379-395.

Aftershock Vulnerability and Time dependent Risk Assessment of Bridges

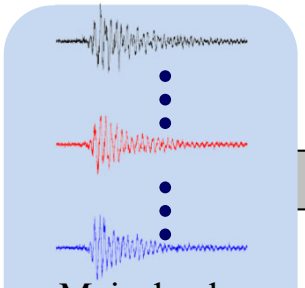
Motivation

- The extent to which 'residual structural capacity' and 'time-dependent aftershock hazard and risk' inform these damage-functionality and inspection priority relationships is unclear.

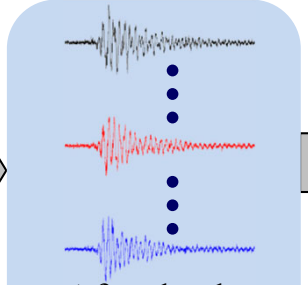
Goals / Overall Objective

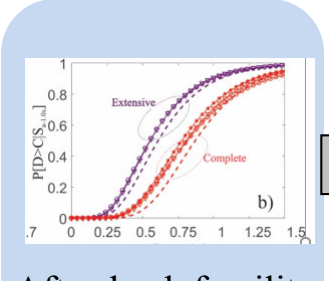
- Conduct aftershock seismic vulnerability and time-dependent risk assessment of typical California bridges
- Evaluate the effect of seismic design philosophy on the time-dependent risk
- Use results from vulnerability and risk assessments to inform decisions regarding the appropriateness and timing of inspections and post-event closure (partial and complete)

Aftershock Vulnerability and Time dependent Risk Assessment of Bridges

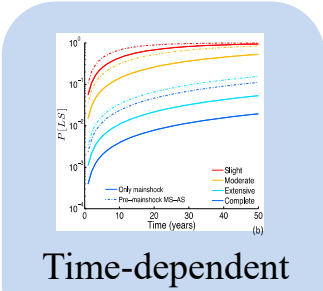

Mainshocks

Damaged Bridge


Aftershocks



Aftershock fragility



Time-dependent hazard and risk

Time-dependent risk and decision-making

Steps involved in proposed framework

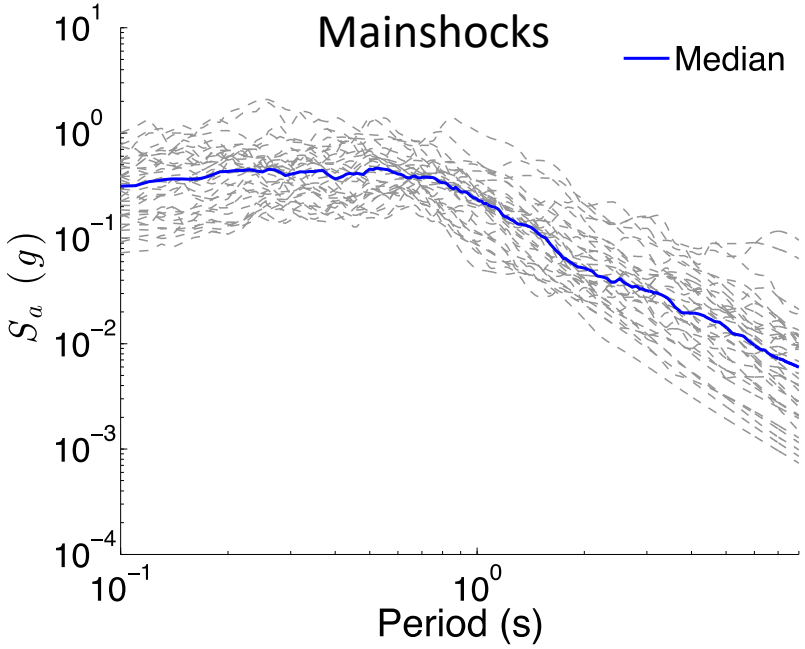
- Select mainshock-aftershock ground motions
- Create structural models of bridge structures
- Conduct mainshock and mainshock-aftershock fragility analysis
- Quantify time-dependent hazard (APSHA) and risk (Markov Chain Models) assessment
- Establish time-dependent risk and functionality/inspection relationships

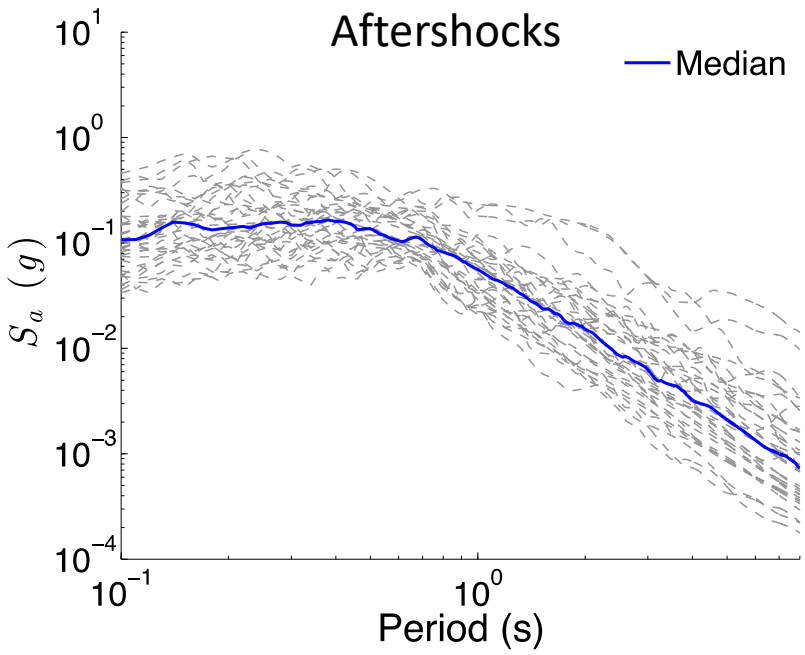
Selection of ground motions

- Past studies have reported non-negligible differences in frequency content of mainshock (MS) and aftershock (AS) records
- Therefore, MS-AS sequences in response history analysis

Mainshock-aftershock ground motions for bridge-specific risk analysis

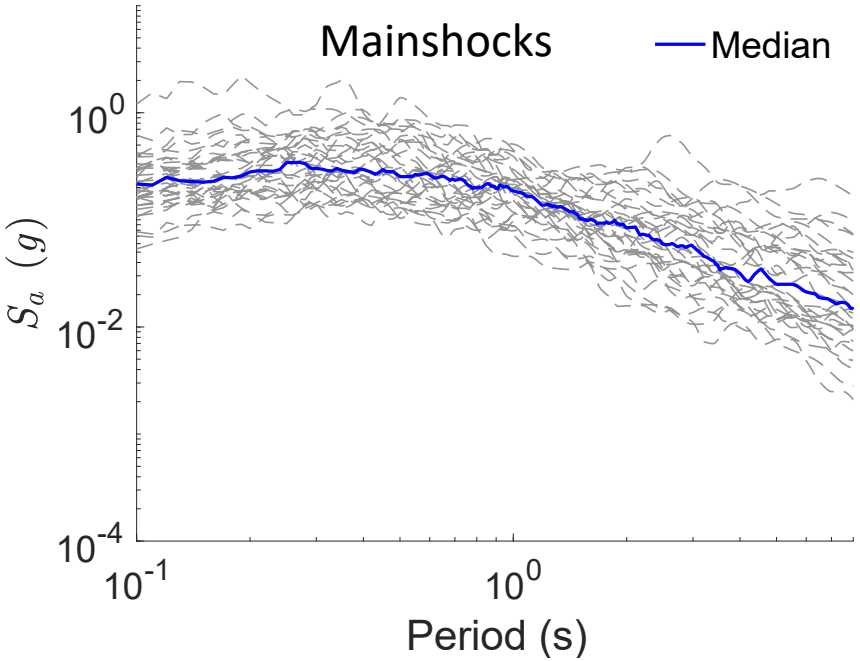
- Selected based on high-seismicity zones in California
- Set of 34 record-pairs from Class 1 and Class 2 events in PEER-NGA West2 database
- $5.8 \leq M_{w,MS} \leq 7.6$
- $4.0 \leq M_{w,AS} \leq 6.5$
- $\varepsilon \sim 1.3$

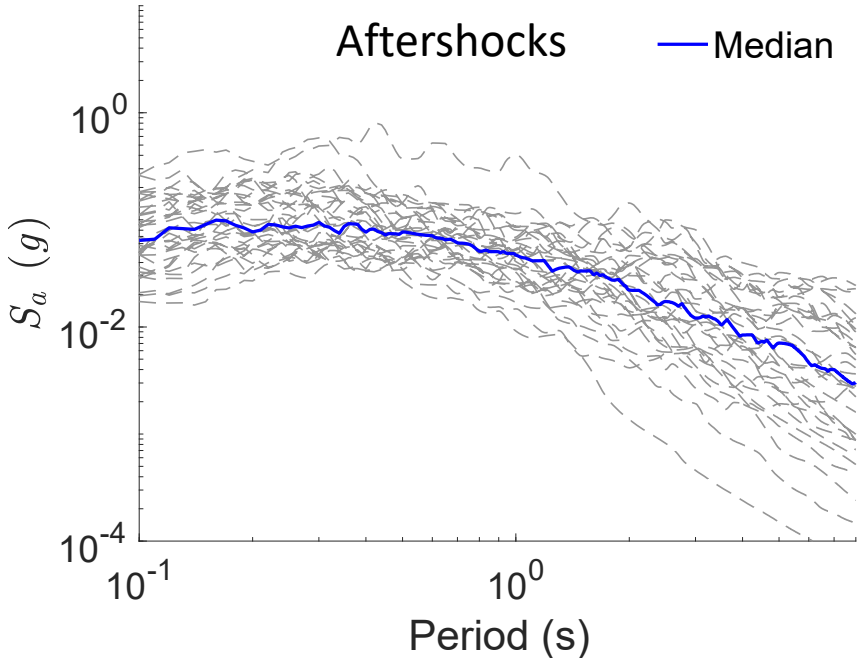




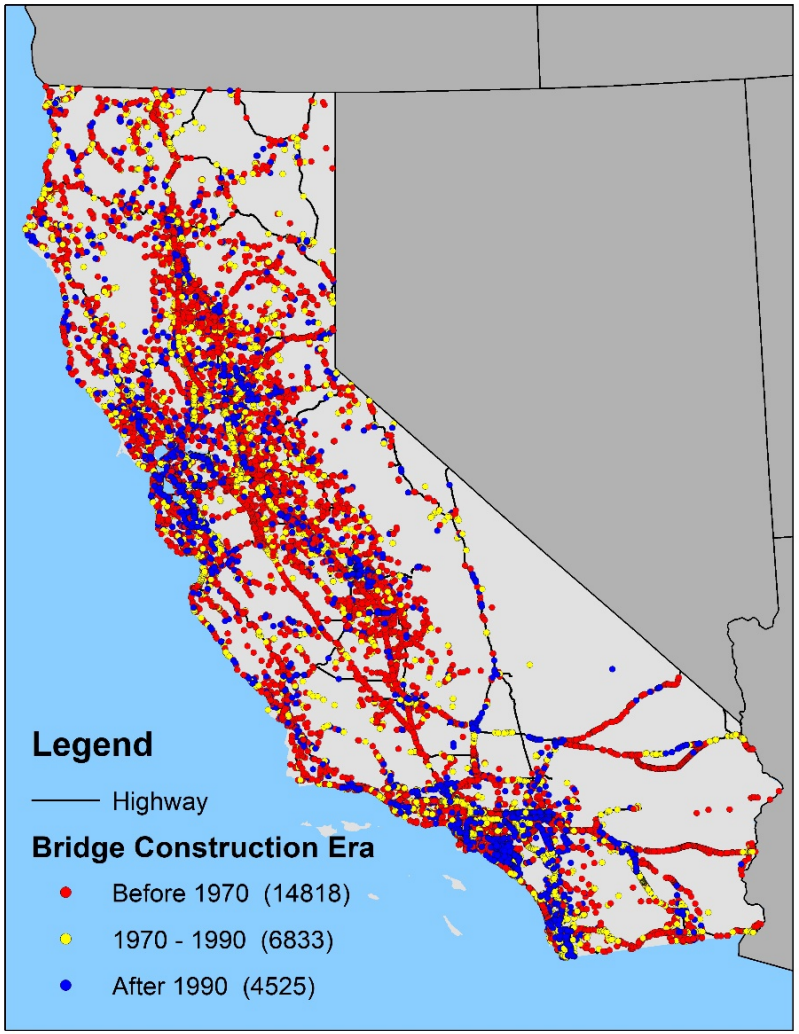
Mainshock-aftershock ground motions for network risk analysis

- Set of 33 record-pairs
- Selected based on a hypothetical scenario event
  - $M_{w,MS} = 7.3$
  - $6.2 \leq M_{w,AS} \leq 7.1$





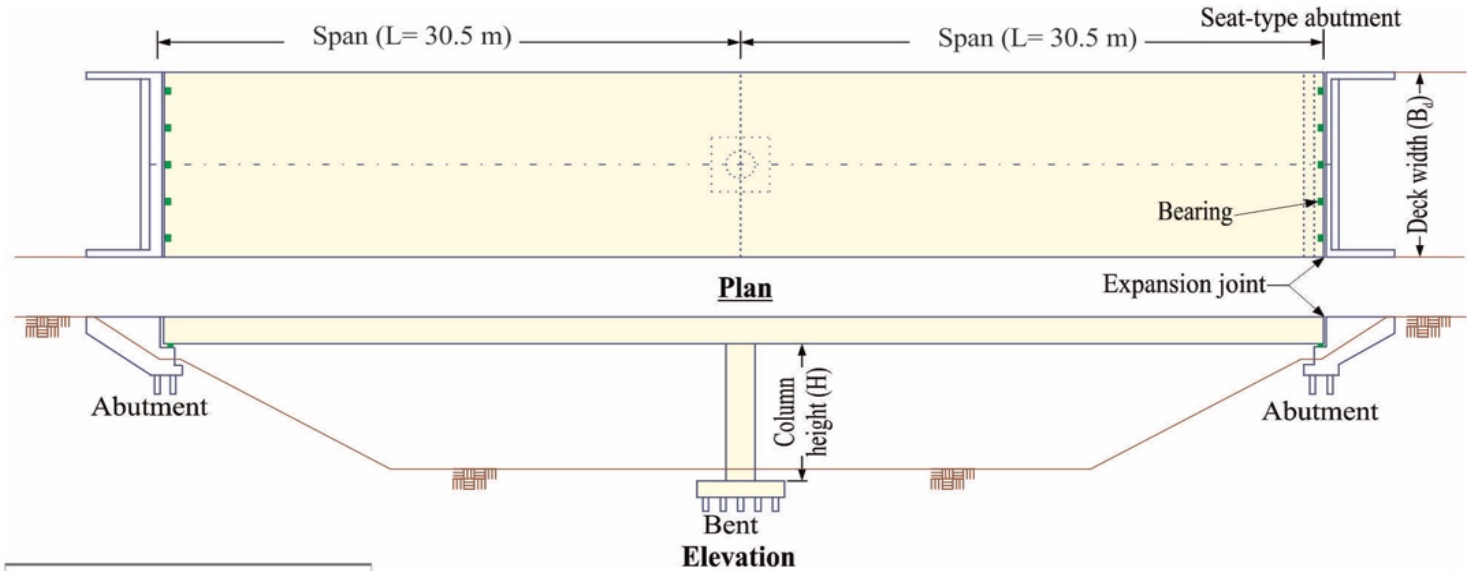
Selected Bridge Cases for various design eras



- More than 24,000 bridges in California
- Mangalathu (2017): based on design philosophy, bridges in California can be grouped into three
  - Era 11 (constructed before 1970)
  - Era 22 (Between 1970-1990)
  - Era 33 (Constructed post 1990)

Mangalathu, S (2017). Performance based grouping and fragility analysis of bridges in California. Ph.D. Thesis. Georgia Tech, USA

Selected Bridge Cases



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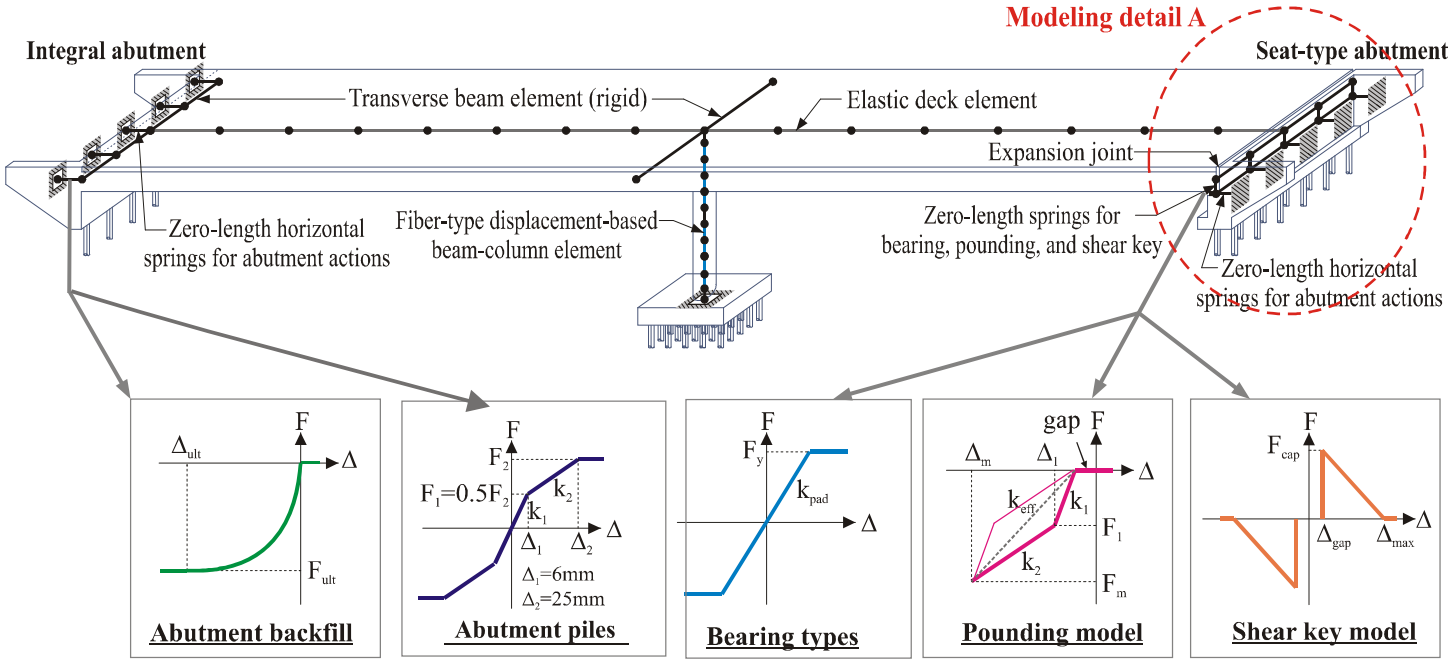
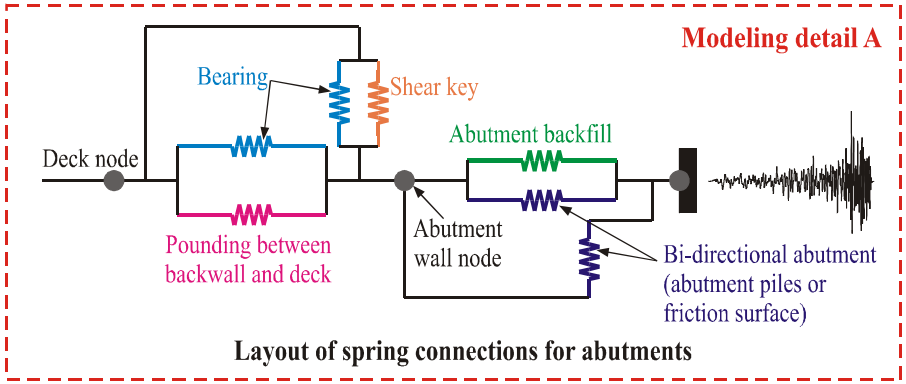
Modeling of Bridge Structures





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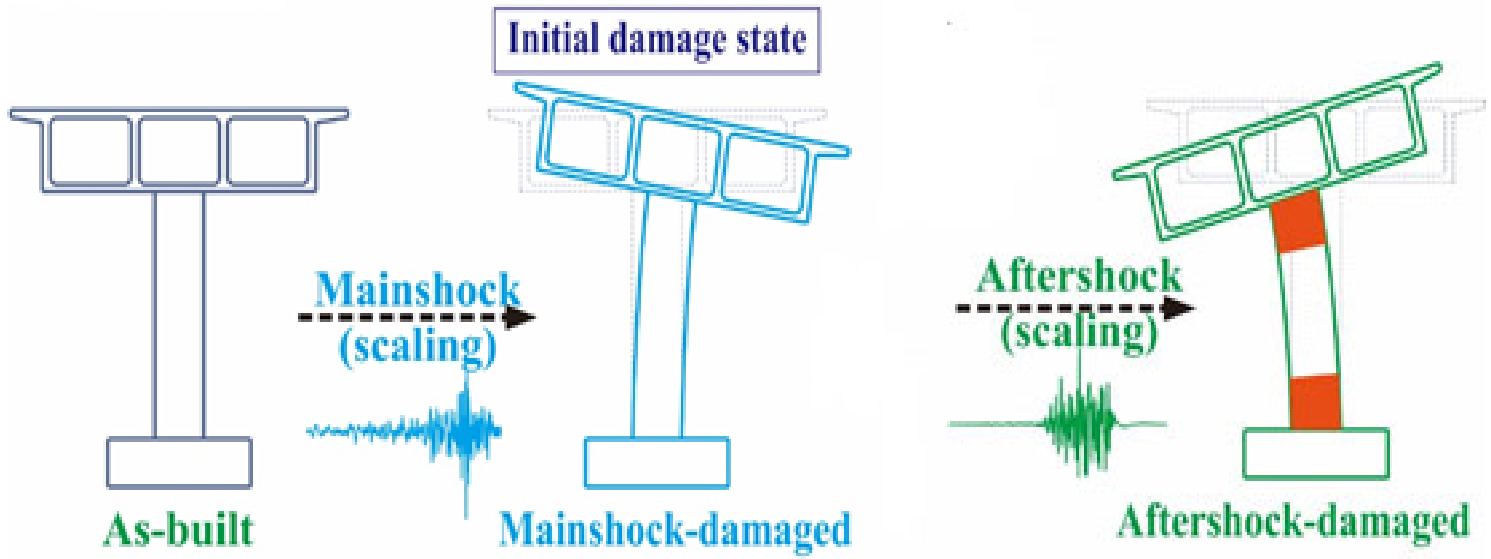
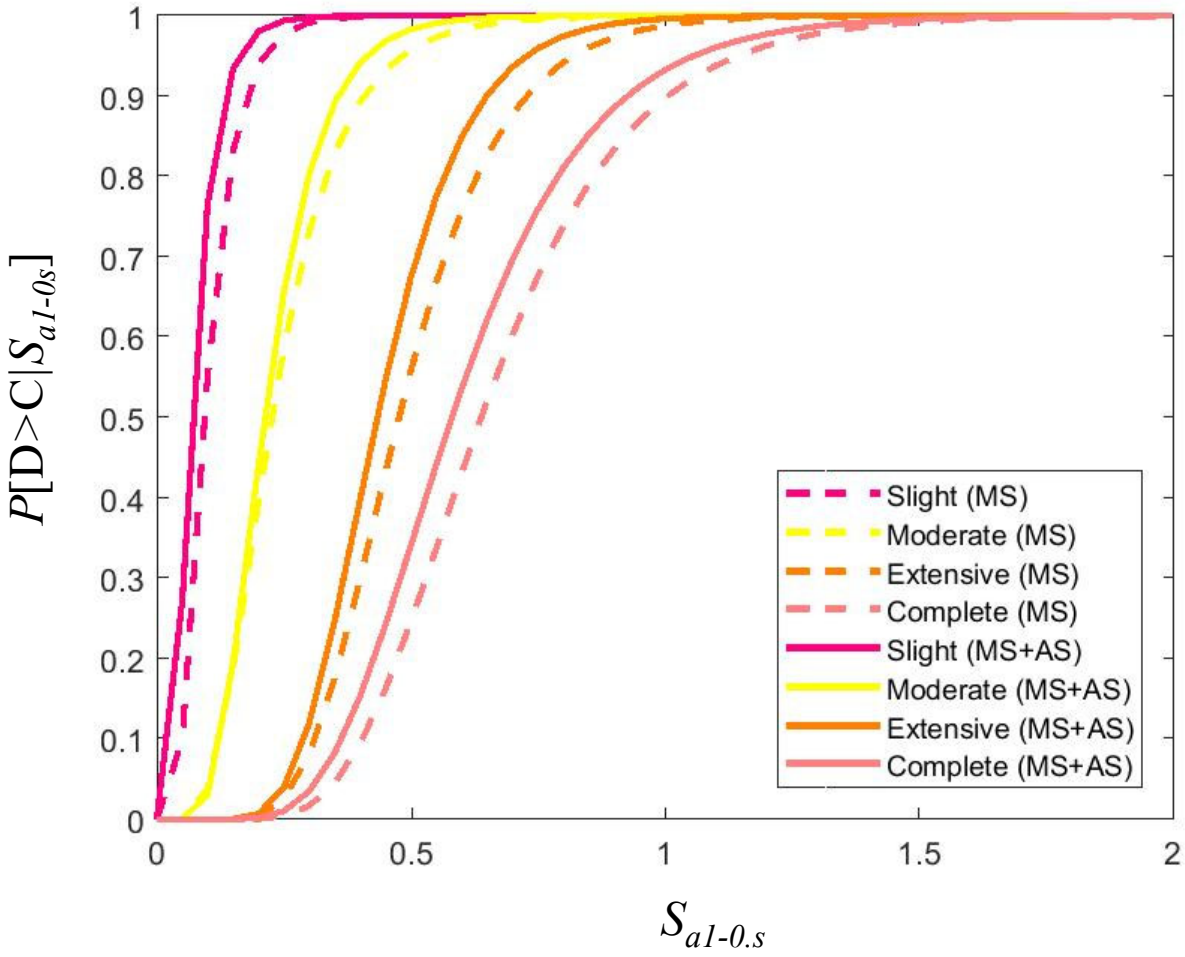
Aftershock Fragility Analysis

- **Aftershock fragility:** A conditional probability that determines the likelihood that a damaged structure will meet or exceed a specified level of damage, given an aftershock intensity measure and an initial damage state associated with the mainshock [**mainshock-damage-dependent aftershock fragility**].



Aftershock Fragility Analysis



Main shock and Aftershock fragilities of a bridge designed in Era 11

Aftershock Vulnerability and Time dependent Risk Assessment of Bridges

A Probabilistic Framework for Quantifying MS and MS-AS Seismic Risk

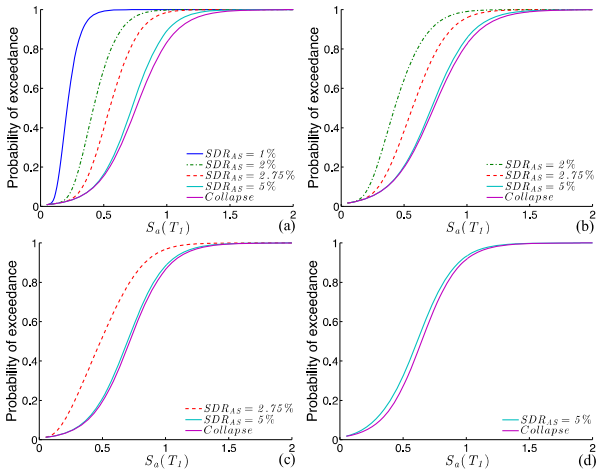
$$\Pi^{k} = \begin{bmatrix} P_{11}^{k} & P_{12}^{k} & \cdots & P_{1r}^{k} \\ 0 & P_{22}^{k} & \cdots & P_{2r}^{k} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & P_{rr}^{k} \end{bmatrix}$$

$$P_{ij}^{k} = \int \left(P_{i,j}\left[EDP > edp_j | IM\right] - P_{i,j+1}\left[EDP > edp_{j+1} | IM\right] \right) d\lambda_{IM}^{k}(im)$$

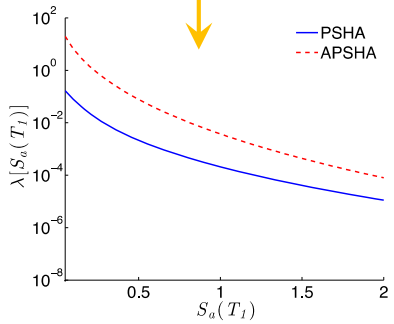
i: damage state under 1st event

j: damage state 2nd event

Probability of transition between limit states at time step k after mainshock

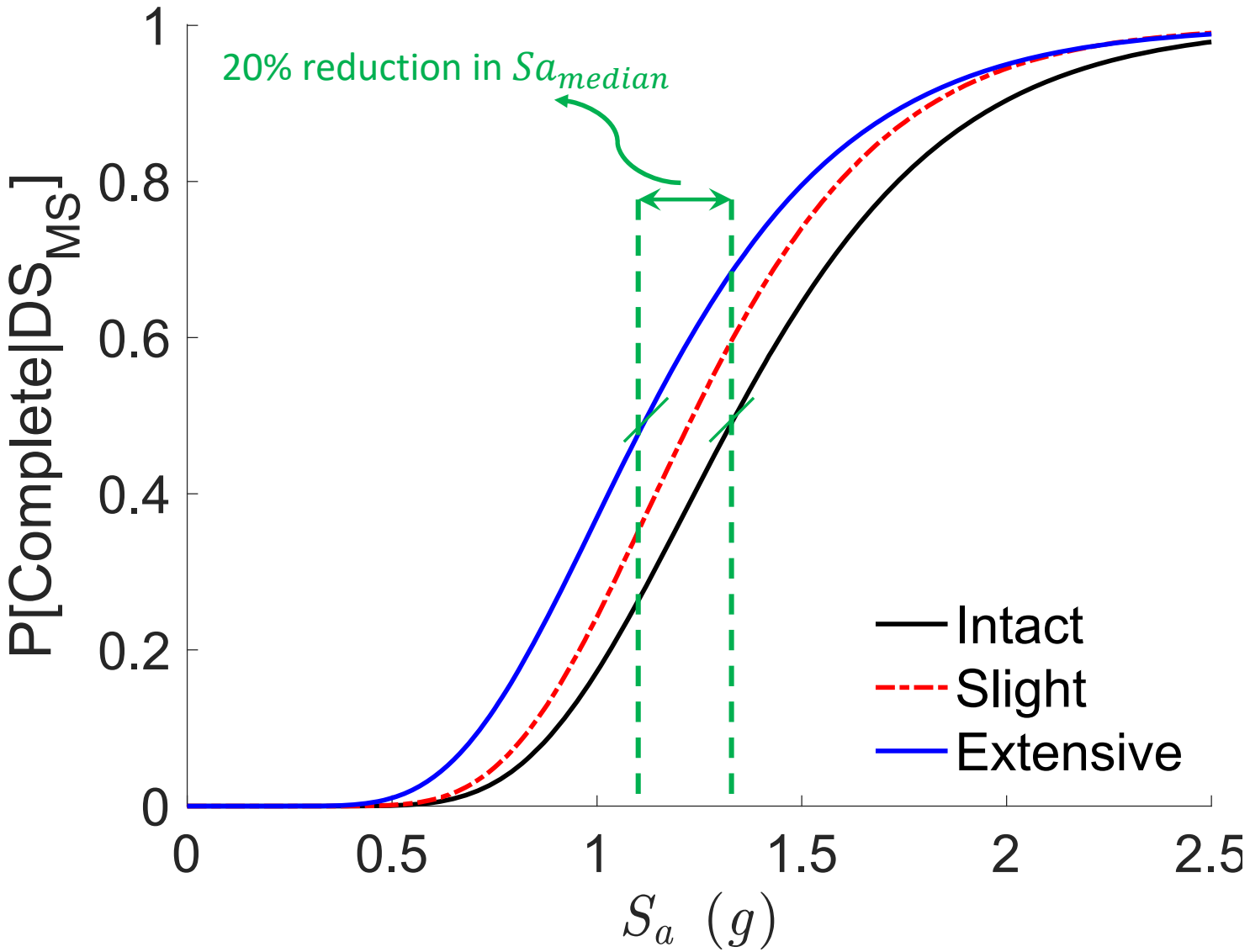


APSHA curve at time step k after mainshock



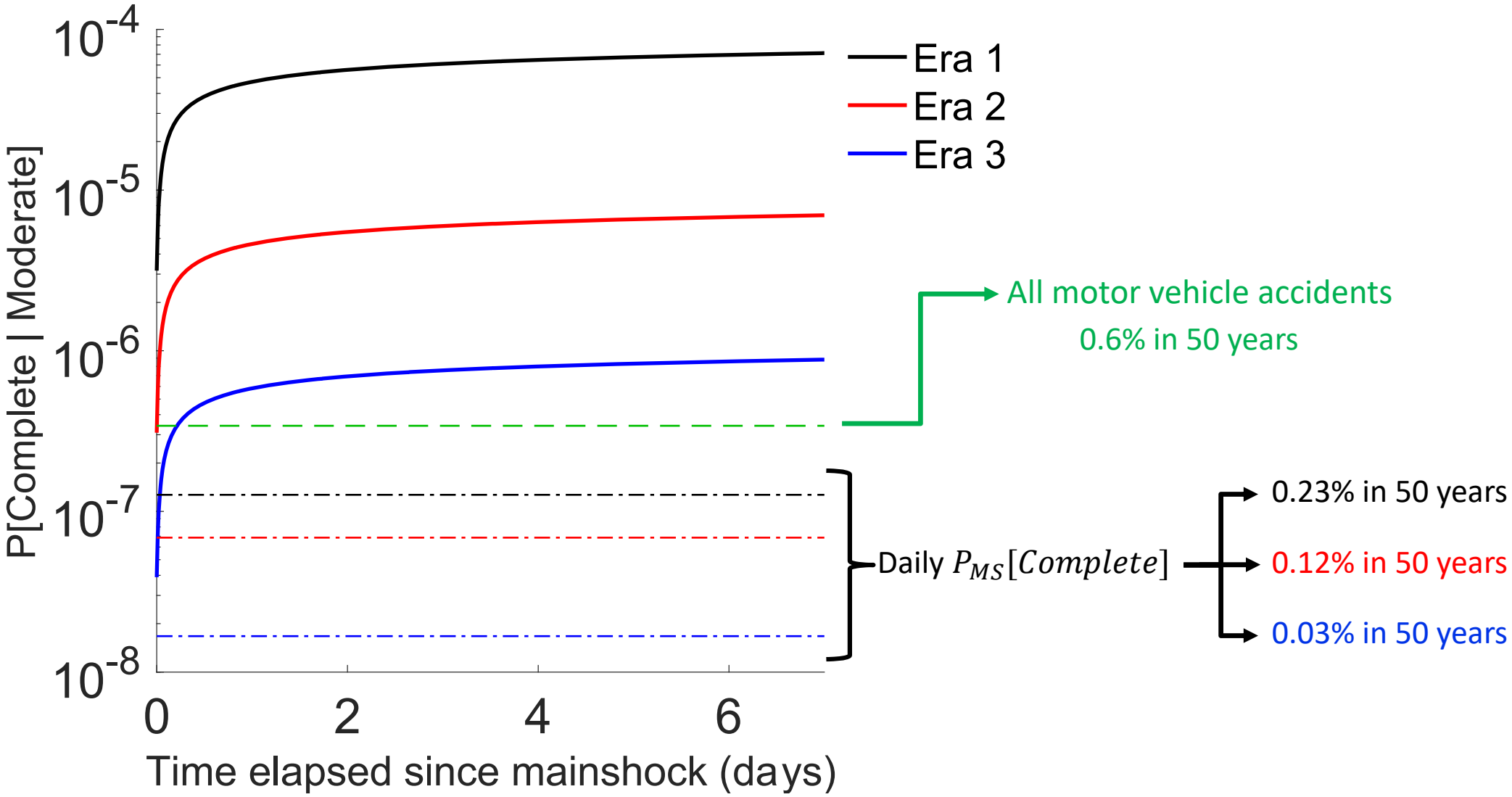
Aftershock Vulnerability and Time dependent Risk Assessment of Bridges

Complete Limit State Probability under Aftershocks for different mainshock limit states and Bridge E3

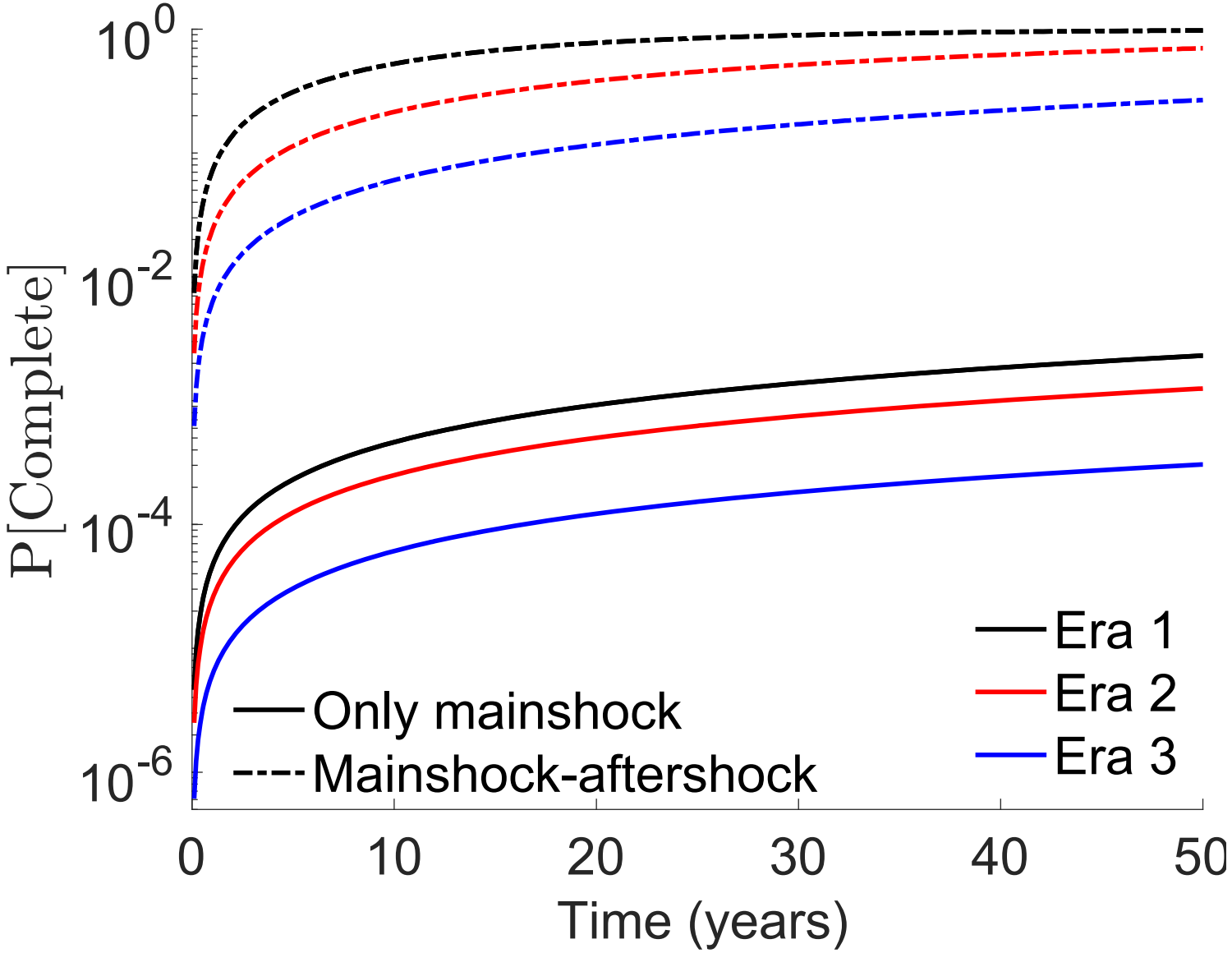


Aftershock Vulnerability and Time dependent Risk Assessment of Bridges

Aftershock Transition Probability conditioned on different limit states under mainshock



Service–life probability of Complete damage state under MS and MS-AS scenarios



Conclusions

- Performed aftershock probabilistic seismic hazard analysis (APSHA) to quantify time-dependent post-mainshock hazard.
- Implemented Markov Chain Model that integrates time-dependent hazard curves and mainshock-damage-dependent-fragilities to quantify time-dependent risk
- Suggested a time-dependent risk outcomes to inform bridge functionality and inspection priorities