A Probabilistic Study to Identify the Effect of Different Damping Modeling Characteristic on the Seismic Response of R/C Bridges

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Introduction

- Modeling energy dissipation is crucial task in nonlinear time history analysis (NTHA) of structures.

- Rayleigh damping is most common method used to represent the energy dissipation in bridges.

- The Rayleigh damping matrix c is given by:

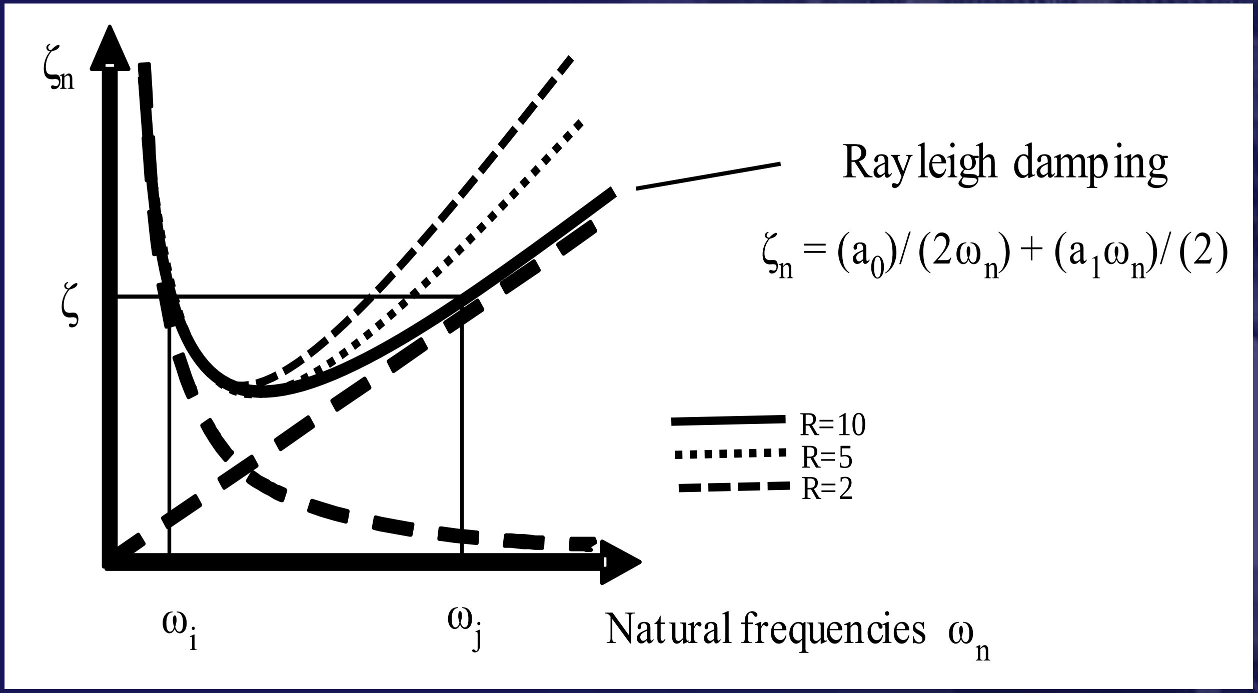
$$\mathbf{c = a_0\, m + a_1\, k}$$

where **m** and **k** are the mass and stiffness matrices of the structure, respectively. If the same damping ratio $\boldsymbol{\zeta}$ is used at two modes with frequencies $\boldsymbol{\omega_i}$ and $\boldsymbol{\omega_j}$, the coefficients $\mathbf{a_0}$ and $\mathbf{a_1}$ are computed as follows:

$$a_0 = \zeta\, (2\omega i\omega j)/\, (\omega i + \omega j) \qquad a_1 = \zeta\, (2)/\, (\omega i + \omega j)$$

Introduction

- Simple variations of Rayleigh damping are stiffness-proportional damping (a_0 = 0), mass-proportional damping (a_1 = 0), and selected frequency ranges.
- Assume frequency range of ω to Rω covering modes of interest (R>1):



Introduction

- **The main advantage** of the Rayleigh is that there is no need to explicitly build and store a damping matrix because mass and stiffness matrices already are stored for other purposes.

- There is **not any reliable reference** to see the consequences of each Rayleigh damping parameter on bridge seismic response assessment.

Study Objectives

- Provide a reference for designers to select Rayleigh damping characteristics based on parameter variation consequences (mainly for performance-based design methodologies)
- Investigate whether findings from previous studies that focused on buildings can be applied to bridges nonlinear time history analysis
- Develop system & component fragility curves for different damping modeling scenarios (considering different sources of uncertainties)

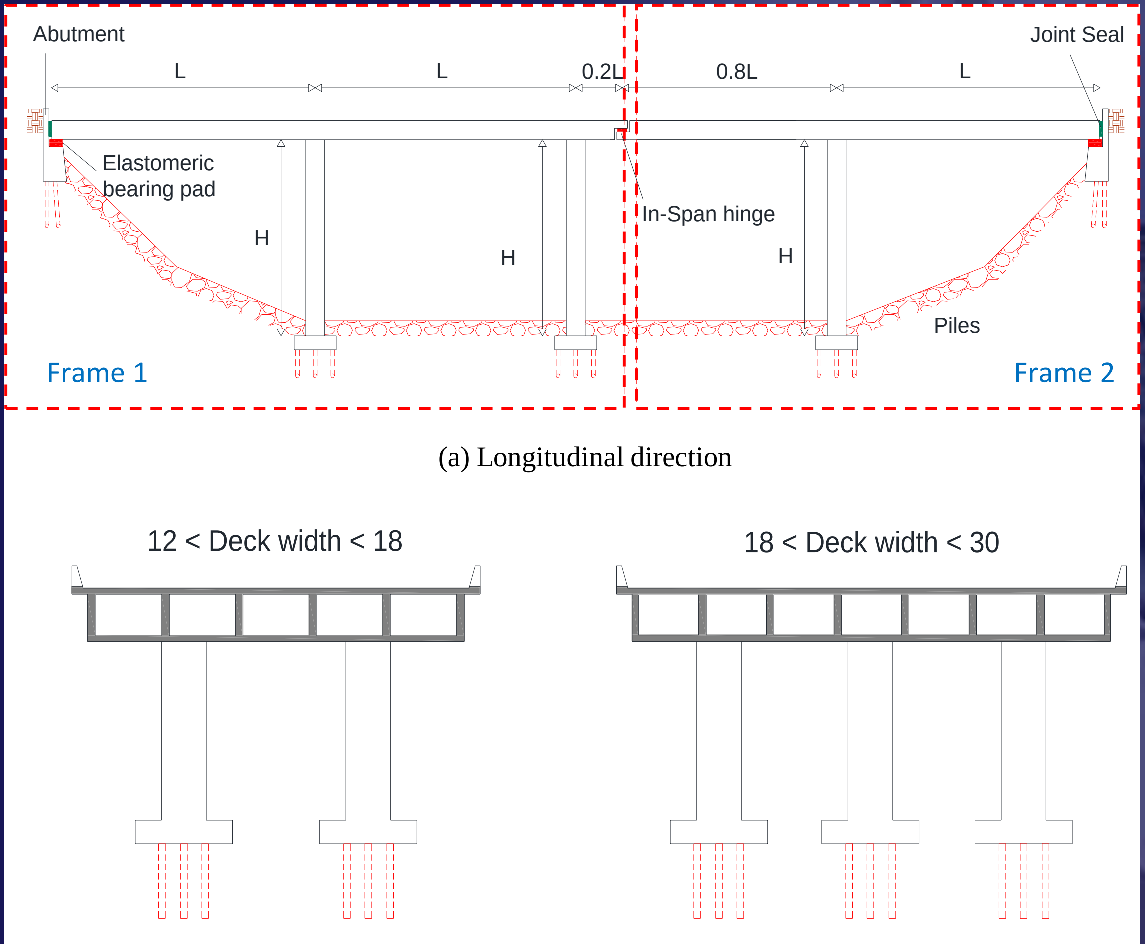
Methodology

- Consider **Four** different damping modeling scenarios:
  - Rayleigh damping with initial stiffness
  - Rayleigh damping with tangent stiffness
  - Stiffness-proportional damping with initial stiffness
  - Stiffness-proportional damping with tangent stiffness
- Consider for each of four scenarios:
  - Three different damping ratios
  - Two frequency ranges in Rayleigh damping modeling
- Conduct NTHA and develop fragility curves

Total of 2400 analysis cases for four-span multi-frame RC box girder bridges (100 bridge sub-classes for each damping modelling characteristic) were generated in OpenSees

BRIDGES CHARACTERISTICS AND MODELING

- **General layout of a typical multi-frame bridge configuration**



(a) Longitudinal direction

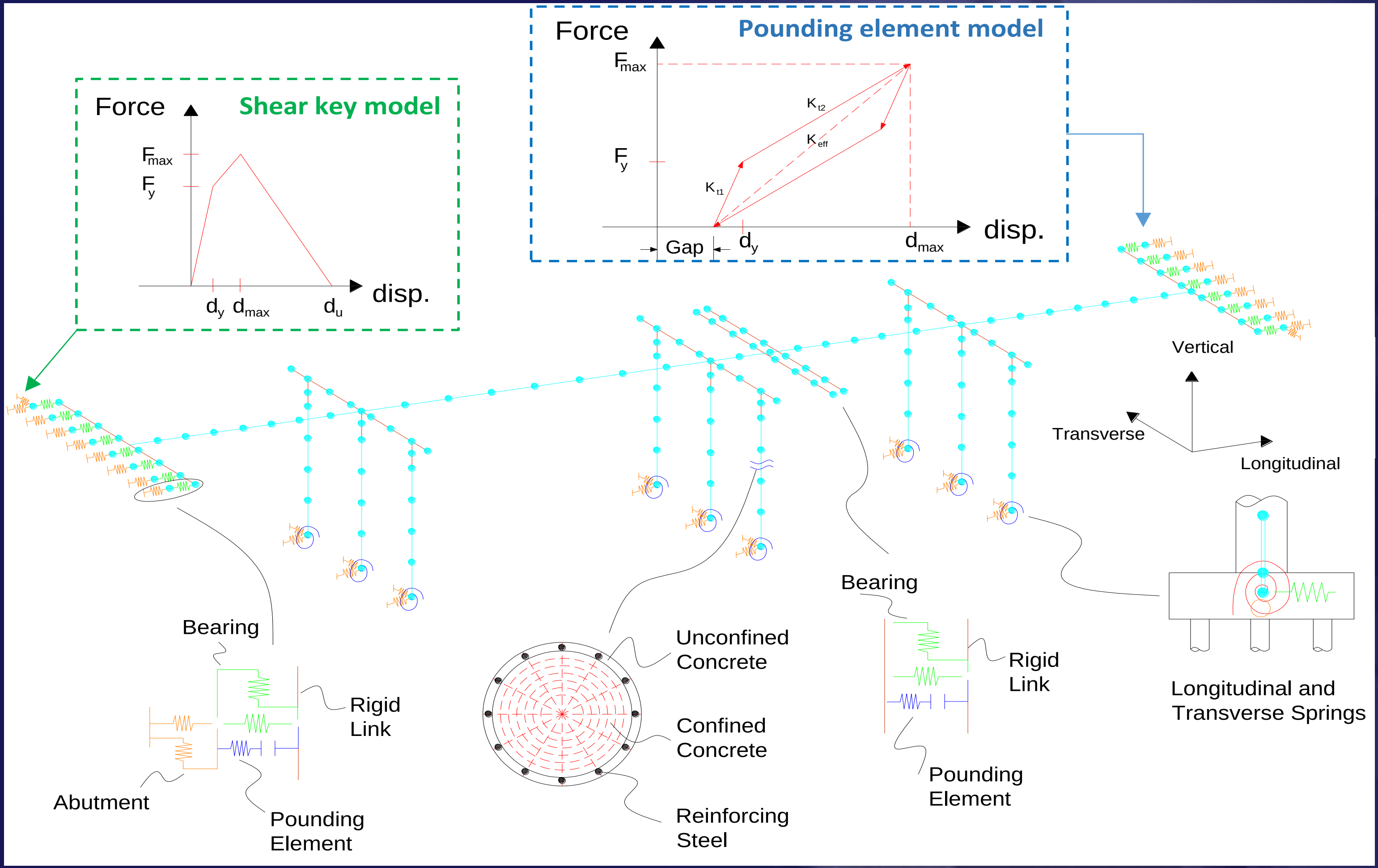
(b) Cross-section

BRIDGES CHARACTERISTICS AND MODELING

- Four-span multi-frame RC box girder bridges with one in-span hinge
- The design details based on earlier (before 1971) Caltrans classification and a review of several actual California bridges plans.
- In-span hinge is the main difference between multi-frame bridges and single-frame bridges.
- Elastomeric bearing pads at seat type abutments and in-span hinge.
- The columns and the superstructure are monolithic.
- Pile caps with a group of piles underneath it.
- External shear keys at two abutment ends.
- Pin connections at column base

Numerical Finite Element Models

3D FE models were developed in OpenSees



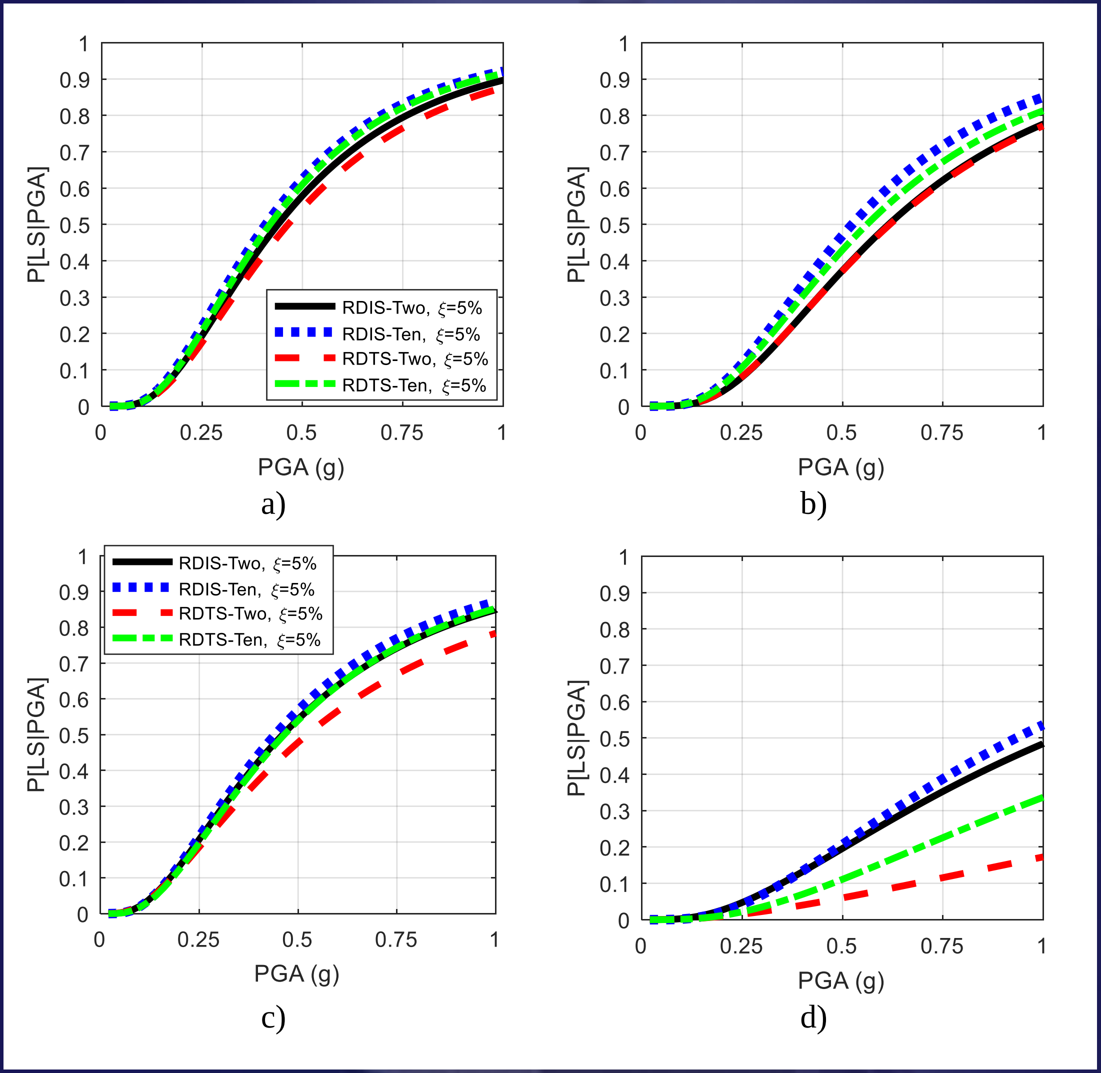
GROUND MOTION RECORDS

- A suite of 100 ground motions was adopted from the Pacific Earthquake Engineering Research Center (PEER) Transportation Research program.
- The set comprises 20 ground motions with strong velocity pulses, which is characteristic of sites experiencing near-fault directivity effects as in California.
- All the ground motions pertain to shallow crustal earthquakes with magnitude ranging from 4.3 to 7.9.
- The incidence angle for each set of orthogonal horizontal component of ground motions and bridge sample is treated as a random variable
- The vertical component of ground motions is ignored.
- This study focuses on a class of bridges rather than an individual bridge, so the intensity measure (IM) of choice is PGA .

RESULTS: frequency range effect

- 5% Damping
- Two vs. ten modes
- Complete Damage State

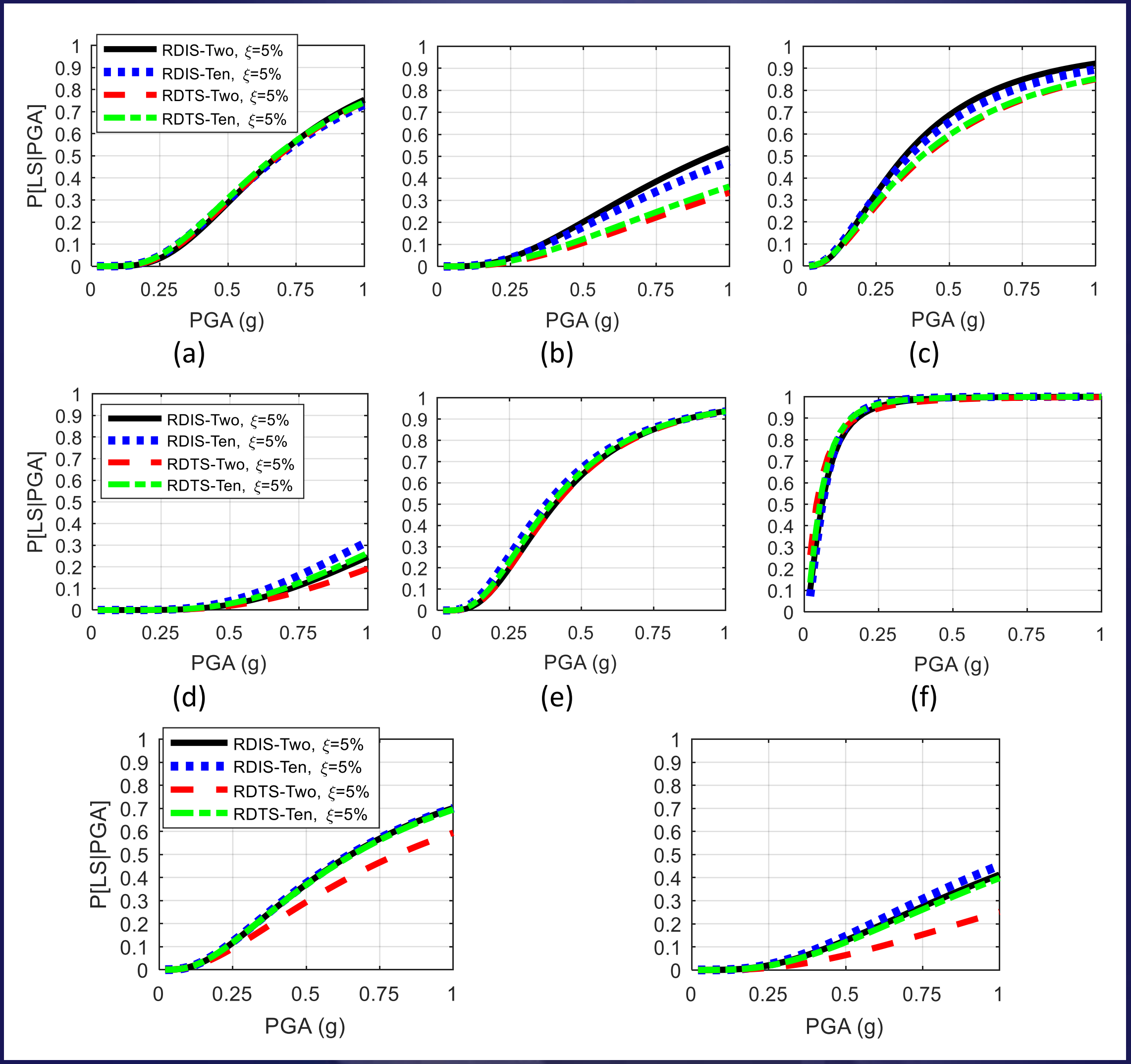
(a) System
(b) Column
(c) Deck unseating (at abutment)
(d) Deck unseating (at in-span hinge)



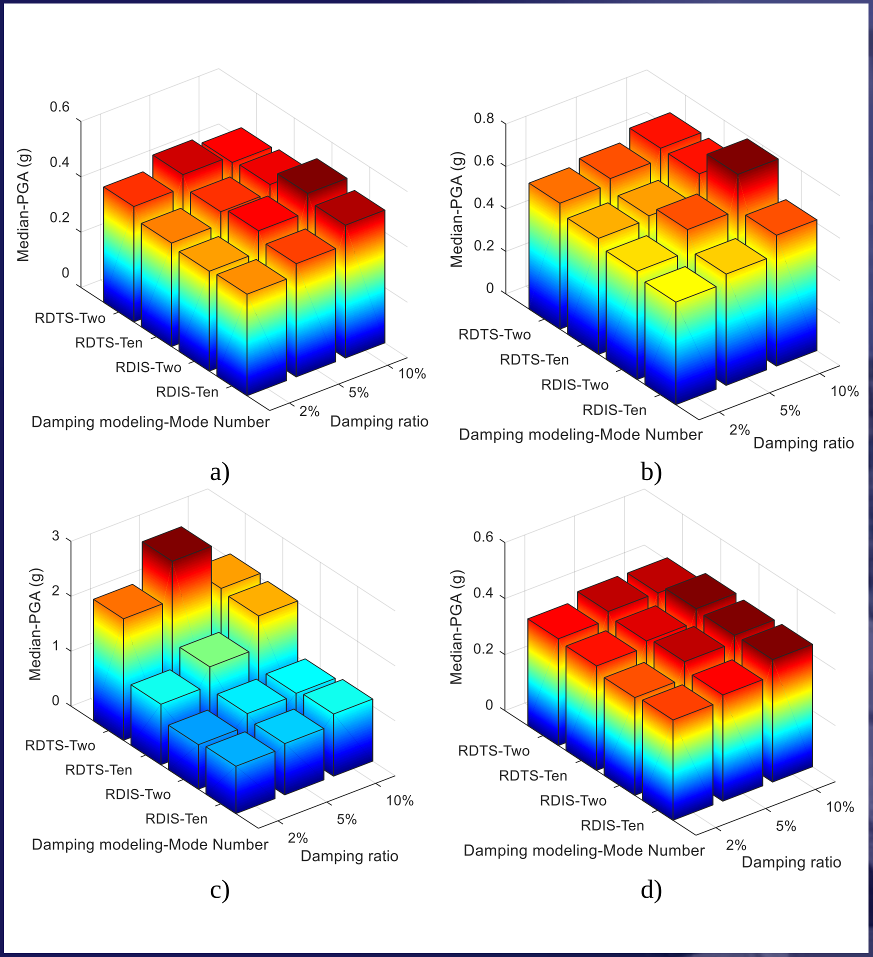
RESULTS: frequency range effect

- 5% Damping
- Two vs. ten modes
- Slight/Moderate Damage State

a) Deck displacement (abutment)
b) Deck displacement (in-span hinge)
c) Bearing (in transverse at in-span hinge)
d) Foundation (rotation)
e) Shear key
f) Joint seal at slight damage state
g) Abutment in active performance
h) Abutment in passive performance



RESULTS: frequency range effect



Median fragilities with different frequency ranges for a) System (complete damage state), b) Column (complete damage state), c) Deck unseating at in-span hinge (Extensive damage state, and d) Shear key (moderate damage state)

RESULTS: frequency range effect

Comparison of different Rayleigh damping cases with respect to the "typical RDIS-Two-5%" [Ratios in percent]

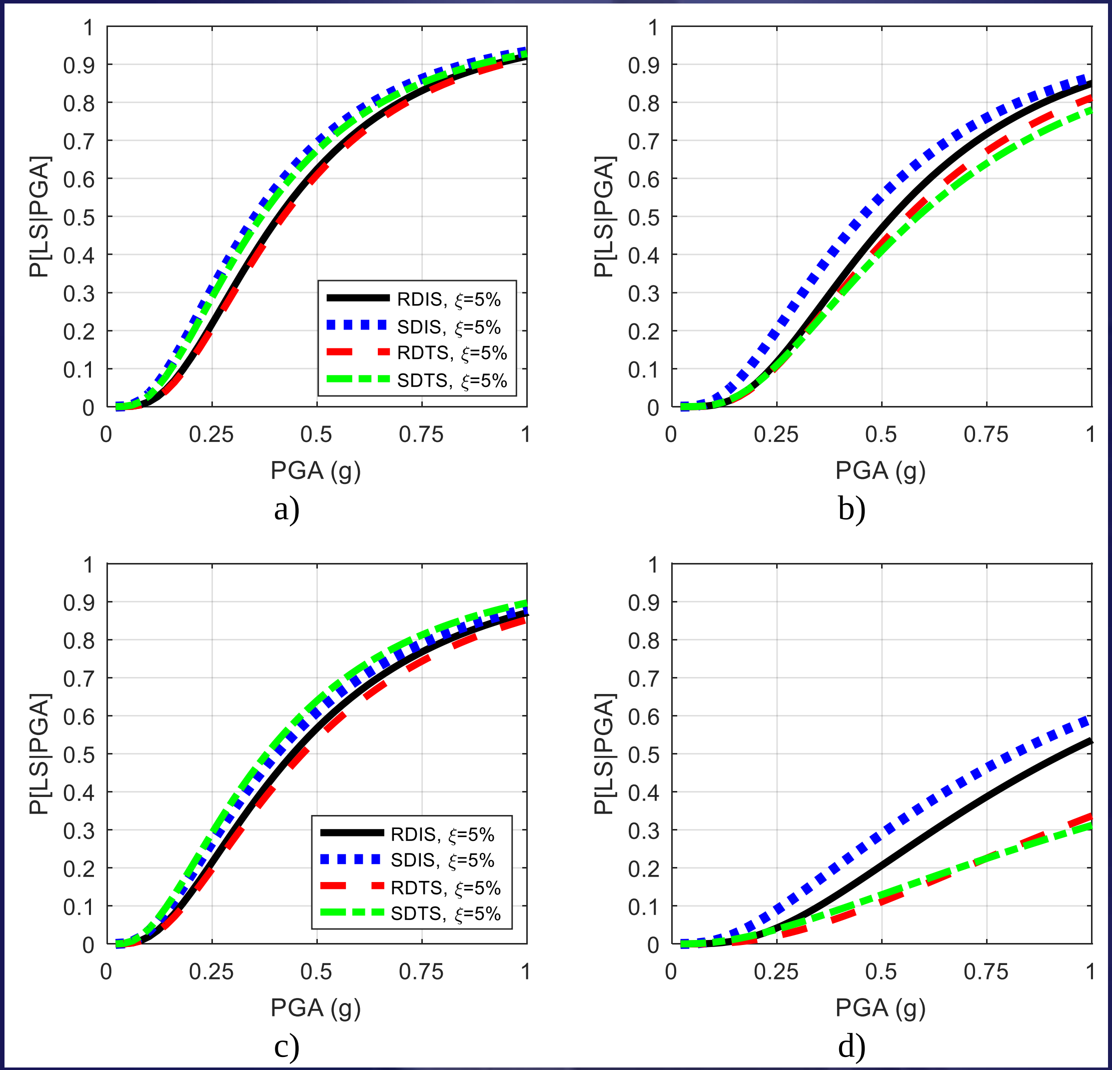
Component-Damage state / Damping characteristic	System-Complete[b]	Column-Complete	Deck unseat-in-span hinge-Extensive	Shear key-moderate
RDTS-Two-2%[a]	5.276	3.710	113.926	7.349
RDTS-Two-5%	5.695	0.488	**182.302**	0.244
RDTS-Two-10%	0.228	8.943	101.451	0.245
RDTS-Ten-2%	17.380	12.637	6.480	9.651
RDTS-Ten-5%	4.773	9.626	39.362	3.807
RDTS-Ten-10%	2.278	8.618	96.035	7.824
RDIS-Two-2%	**21.607**	20.588	27.654	**17.192**
RDIS -Two-5%	0.000	0.000	0.000	0.000
RDIS -Two-10%	15.262	**27.480**	2.708	6.357
RDIS-Ten-2%[c]	19.619	27.329	19.954	14.246
RDIS -Ten-5%	7.335	17.366	10.825	7.916
RDIS -Ten-10%	9.339	0.163	9.381	6.846

a: Rayleigh damping with tangent stiffness, the first two frequency range, and 2% damping ratio
b: System fragility curve at complete damage state
c: Rayleigh damping with initial stiffness, the first ten frequency range, and 2% damping ratio

RESULTS: mass & stiff. prop. effect

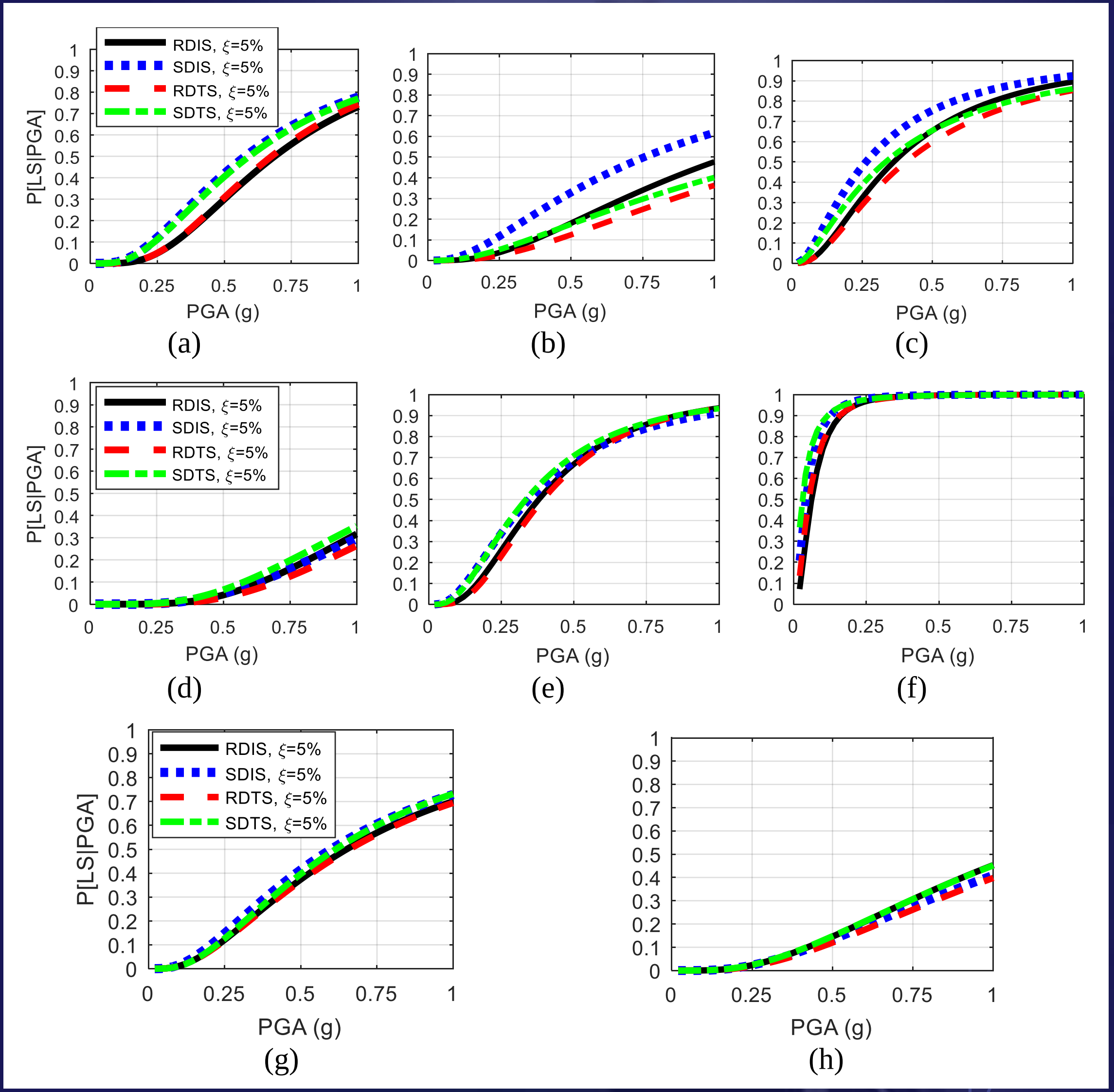
- 5% Damping
- First ten modes

a) System at complete damage state
b) Column at complete damage state
c) Deck unseating (abutment) at extensive damage state,
d) Deck unseating (at in-span hinge) at extensive damage state



RESULTS: mass & stiff. prop. effect

- 5% Damping
- First ten modes
- Moderate Damage State

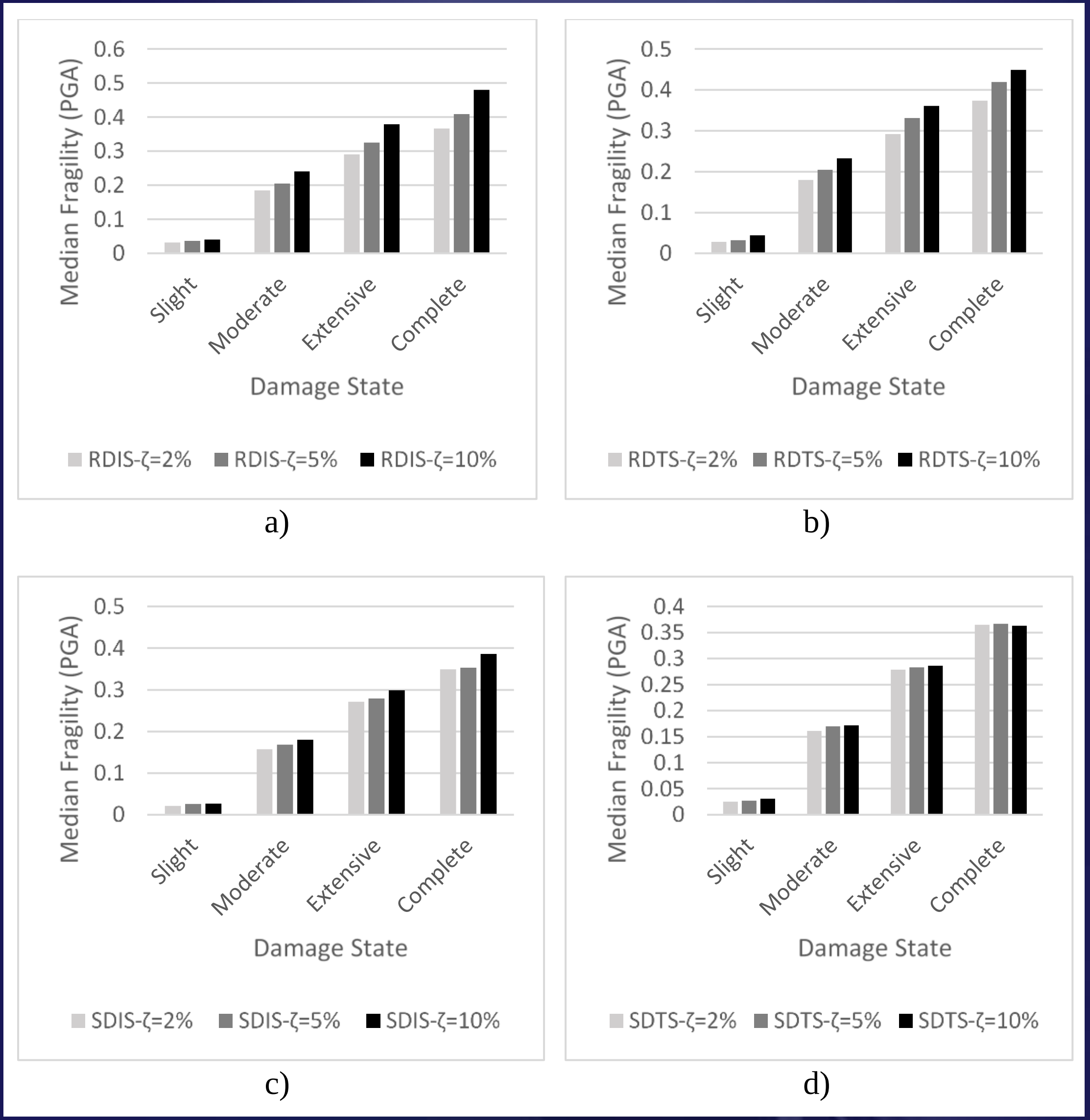


a) a) Deck displacement at abutment
b) Deck displacement at in-span hinge)
c) Bearing (in transverse at in-span hinge)
d) Foundation (rotation)
e) Shear key
f) Joint seal at slight damage state
g) Abutment (active)
h) Abutment (passive)

RESULTS: damping ratio effect

System fragility medians at different damping ratios for:

a) RDIS
b) SDIS
c) RDTS
d) SDTS



Conclusions

- Components & system fragility showed different sensitivity to changing damping characteristics across all damage states.
- Higher modes effect is significant and it should be consider in estimating Rayleigh damping coefficients (e.g. fragility medians varied by 102.5% for deck unseating at in-span hinge when 2 vs 10 modes are considered.
- System fragility is more sensitive to ignoring the mass-proportional part of Rayleigh damping & some component fragility are affected by stiffness matrices
- RDIS and SDTS showed highest and lowest sensitivity to changing damping ratio, respectively.
- Deck unseating at in-span hinge is most sensitive component to changing Rayleigh damping characteristics.

Thank You! Questions?