Utilization of Seismic Instruments Data in Assessing Building Code Provisions

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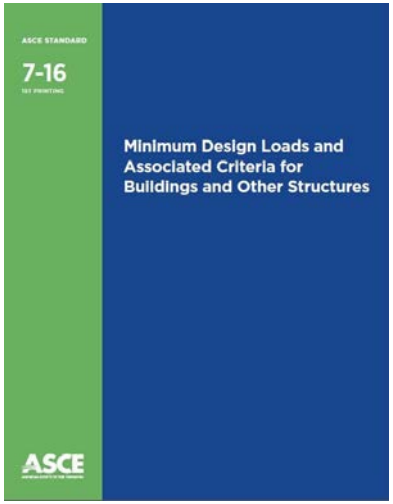
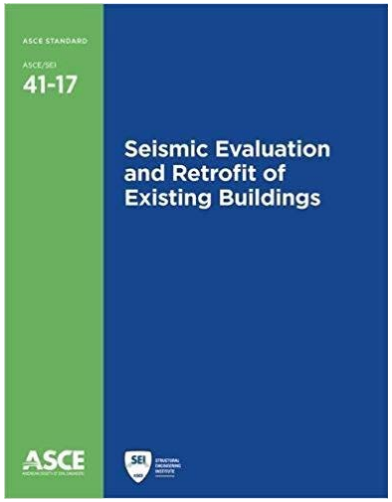
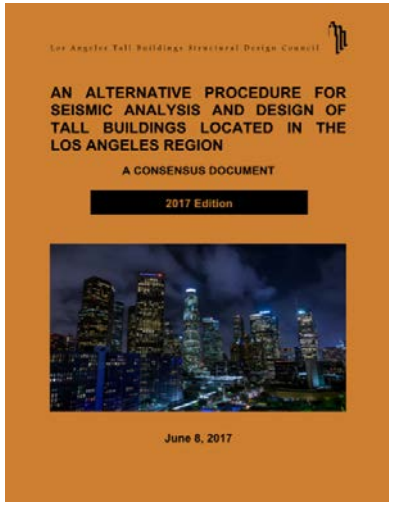
Farzin Zareian

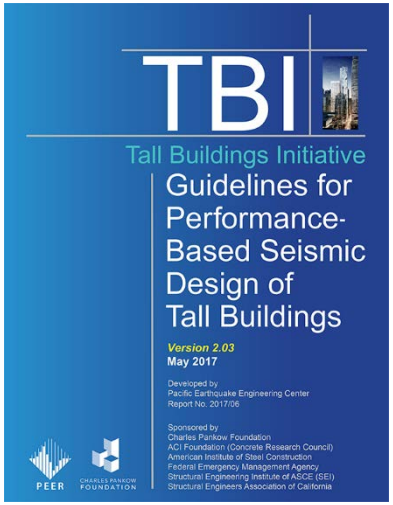
UC-Irvine

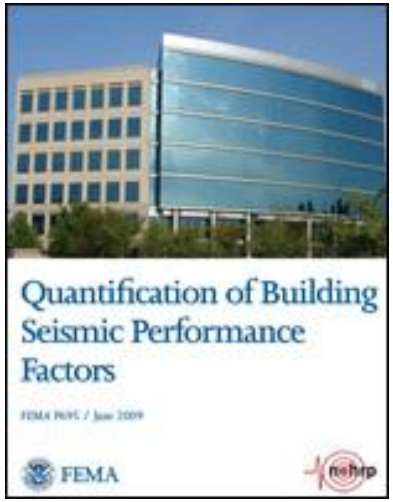
Seismic Design and Assessment Documents



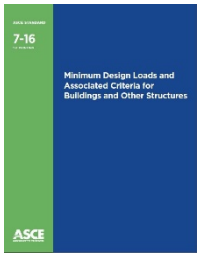


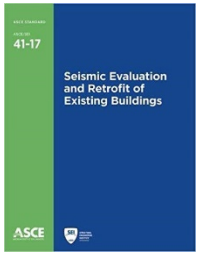


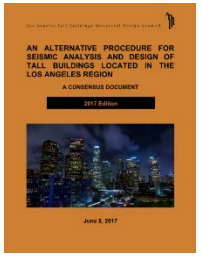




Outline

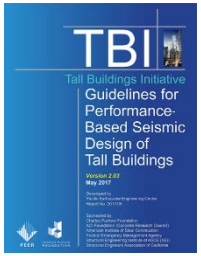






- Accomplishments in utilizing instruments data in assessing code provisions:
  - Natural Periods and Equivalent Damping Ratios
  - Accidental Torsion

- Current/Future directions



Current Code Provision

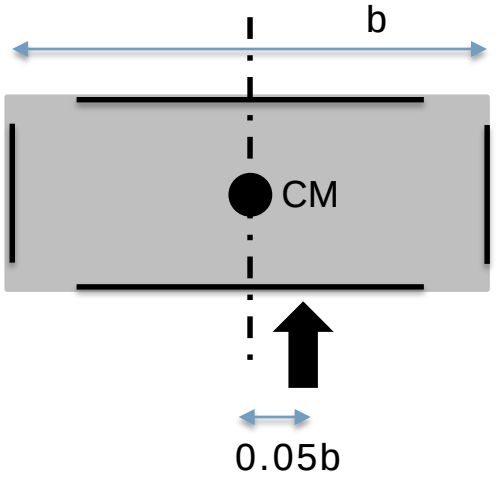
- Natural Period
  - $T_a = C_t h_n^x$
    (ASCE 7-10)

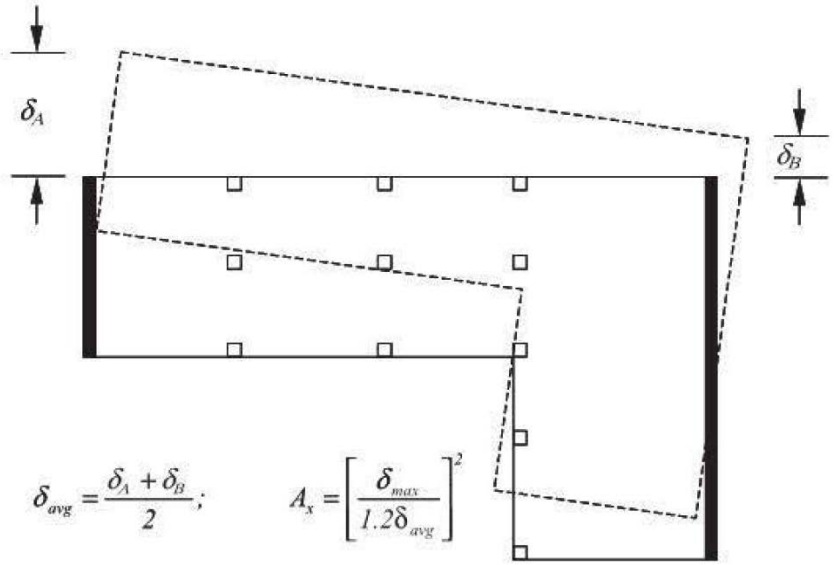
Structure Type	C_t	x
Steel Moment Resisting Frames	0.028	0.8
Concrete Moment Resisting Frames	0.016	0.9
Steel Eccentrically Braced Frames	0.03	0.75
Steel Buckling Restrained Braced Frames	0.03	0.75
All Other Structural Systems	0.02	0.75

- Equivalent Modal Damping Ratio
  - ASCE 7-10 uses 5% damped response spectrum
  - FEMA P-58-1 suggests 1% to 5% of critical damping in the predominant vibration modes of the structure
  - FEMA P-58-1 suggests that damping ratio values of 3% or less should be used for tall buildings

Current Code Provision

- Accidental Torsion
  - ASCE 7-10: "…accidental torsional moments caused by assumed displacement of the center of mass each way from its actual location by a distance equal to **5 percent** of the dimension of the structure perpendicular to the direction of the applied forces."



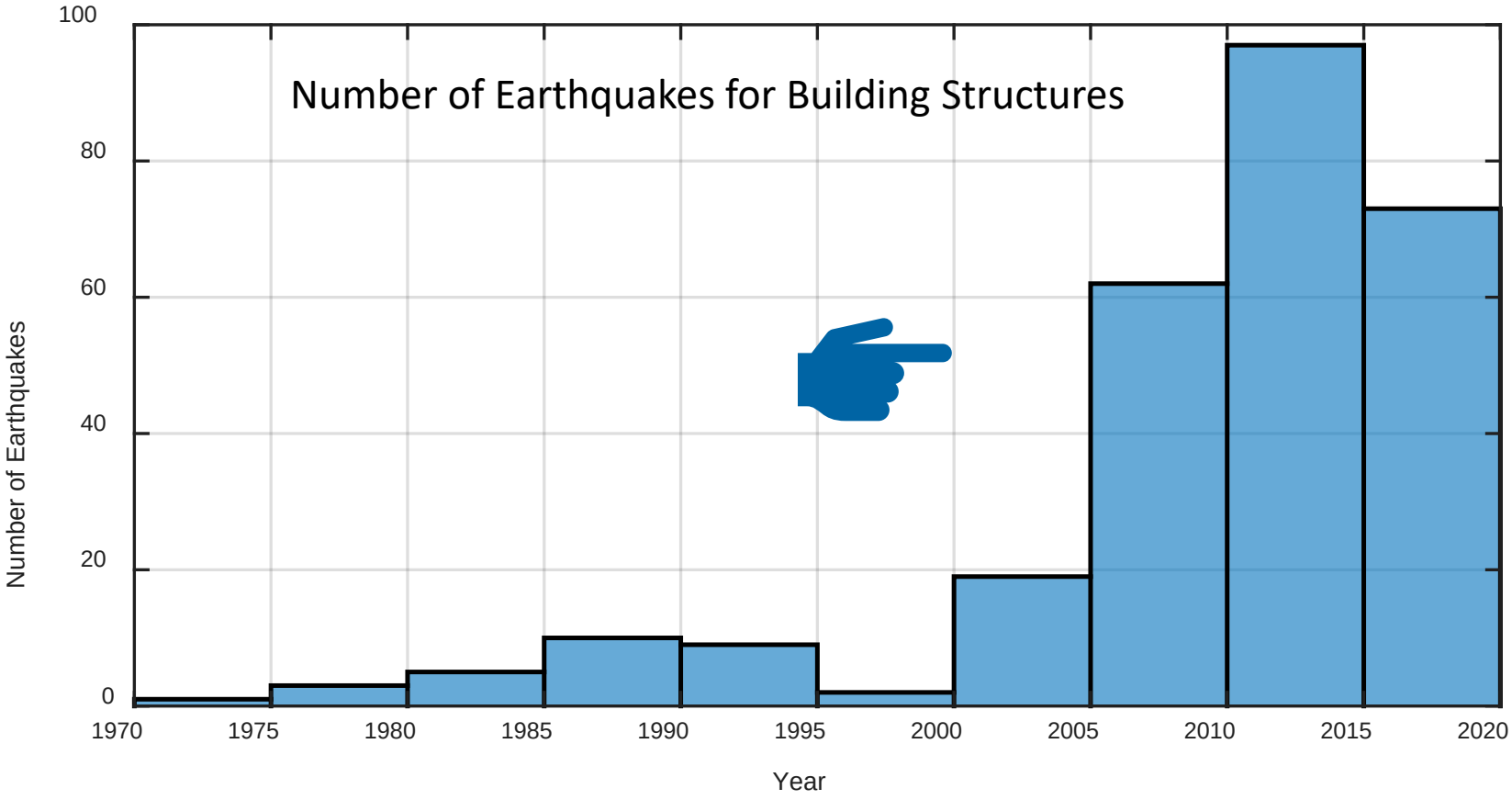


$1.4 > \delta_A/\delta_{avg} > 1.2$ Type 1a

$\delta_A/\delta_{avg} > 1.4$ Type 1b

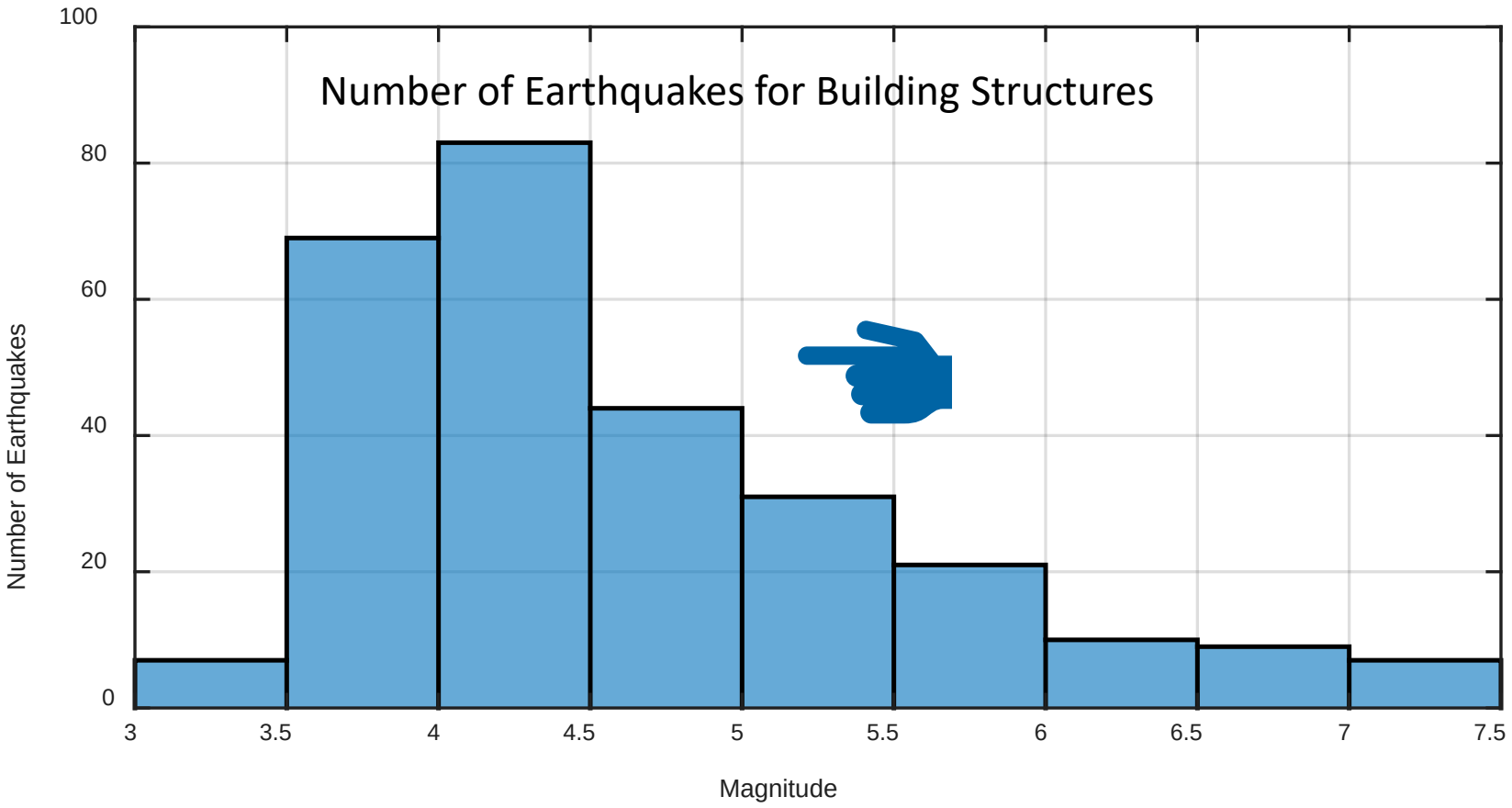
CSMIP Database

California
Department of Conservation



CSMIP Database

California
Department of Conservation



CSMIP Database

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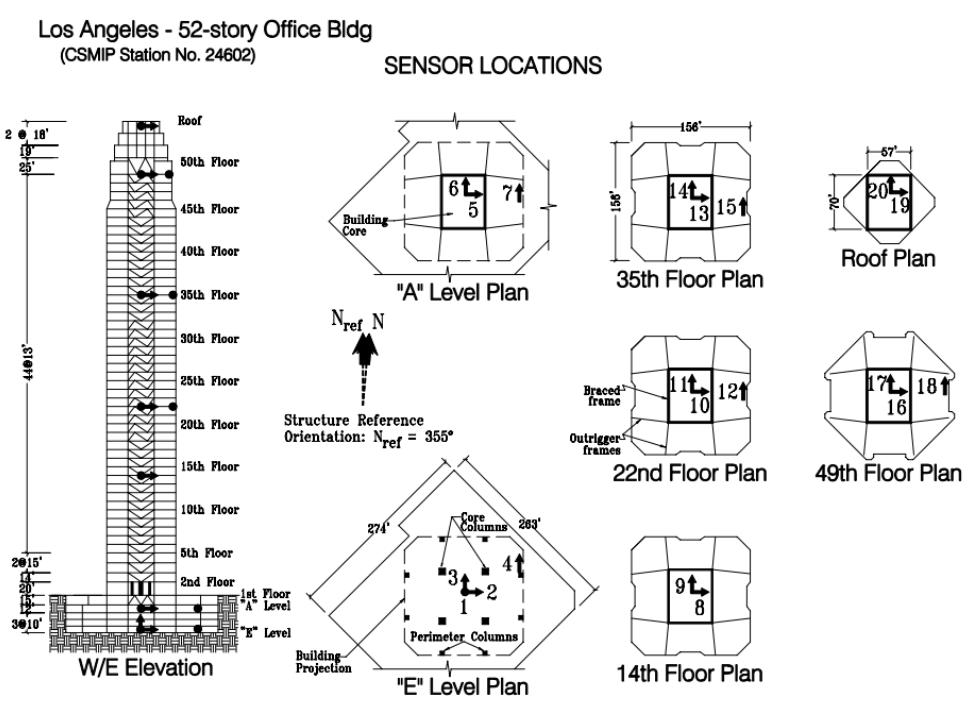
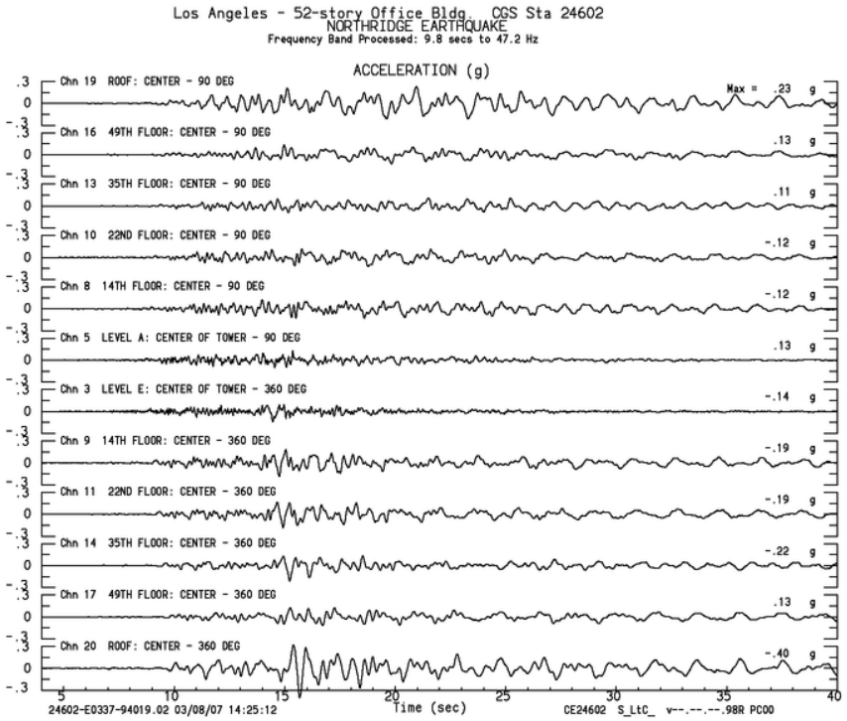
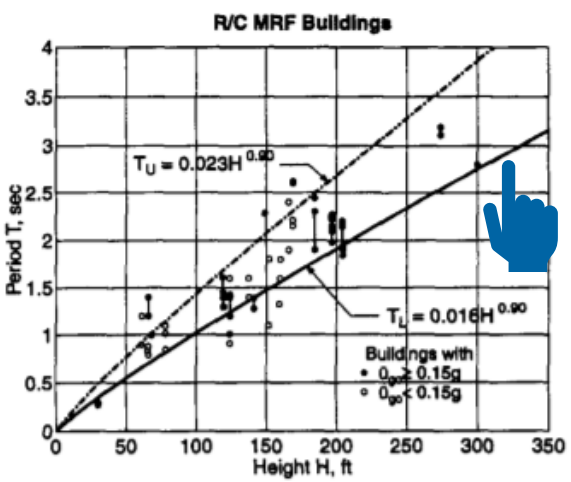
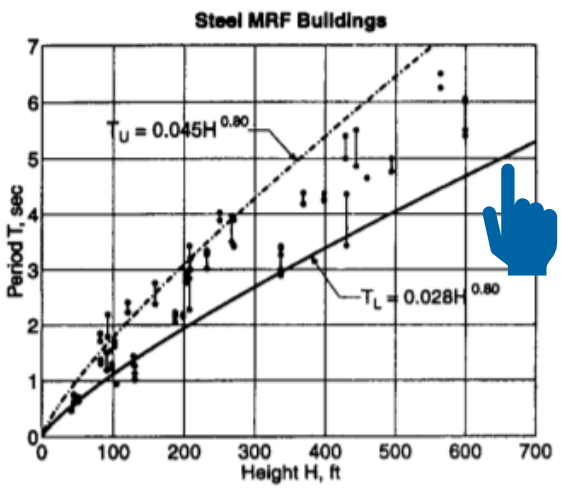


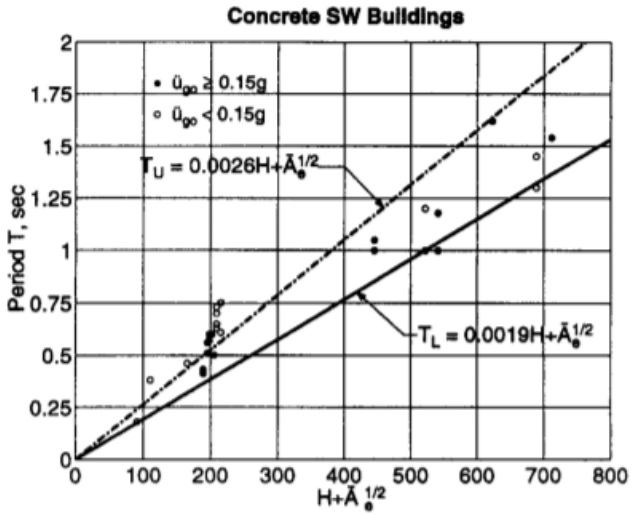


Modal Properties: previous research

- Natural Period
  - Goel, R., & Chopra, A.K. (1997). “Period formulas for moment-resisting frame buildings”.
  - Goel, R., & Chopra, A.K. (1998). “Period formulas for concrete shear wall frame buildings”.



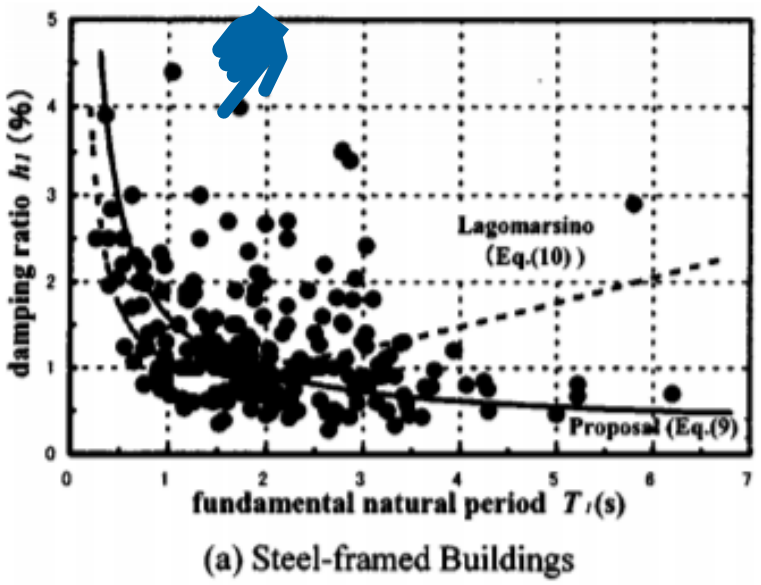




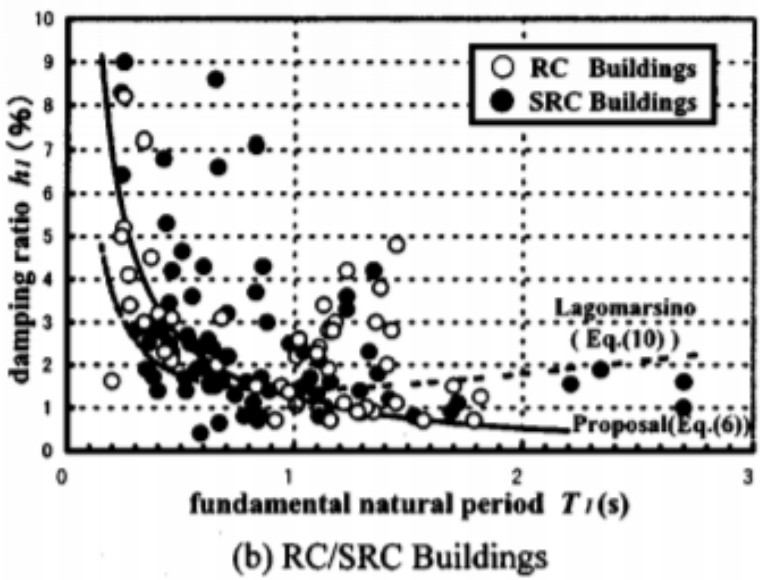
These Equations are implemented in ASCE code provision

Modal Properties: previous research

- Equivalent Modal Damping Ratio
  - Satake *et al*. (2003). "Damping Evaluation Using Full-Scale Data of Building in Japan".



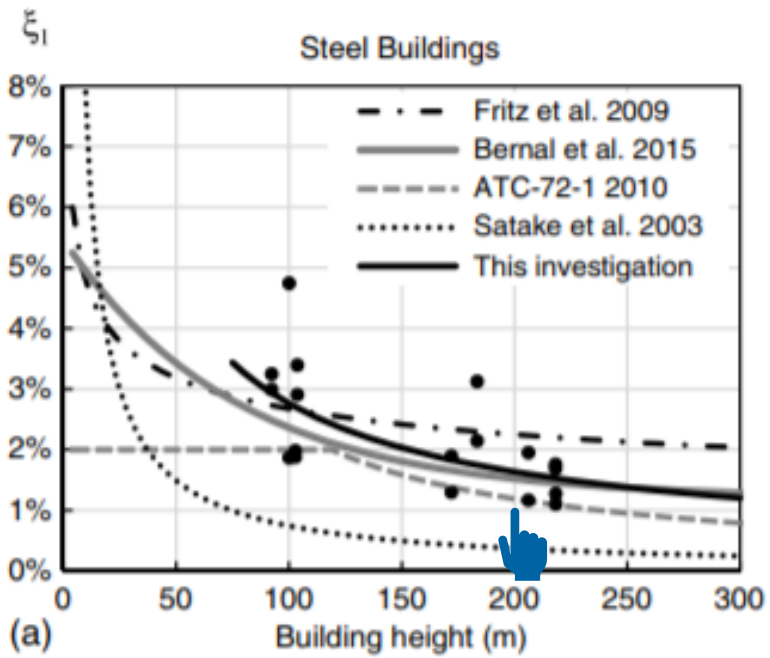
(a) Steel-framed Buildings

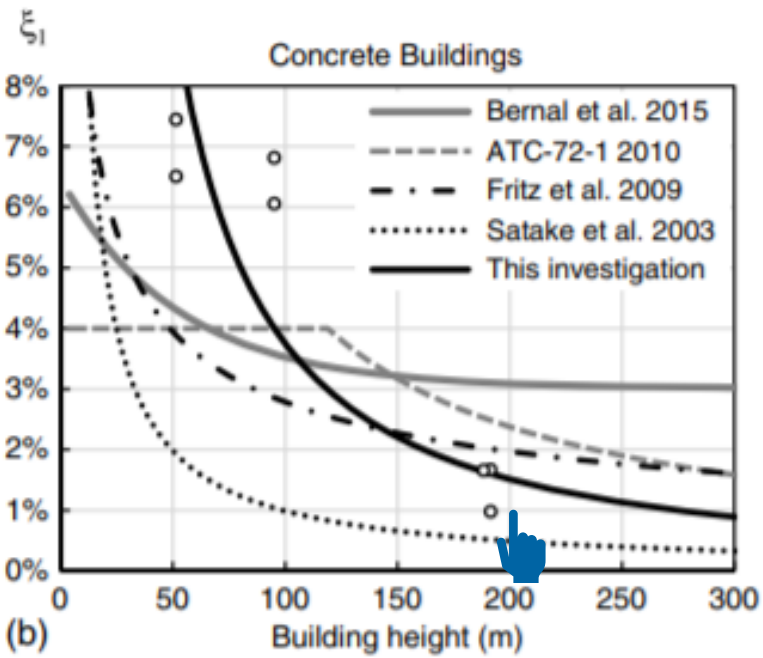


(b) RC/SRC Buildings

Modal Properties: previous research

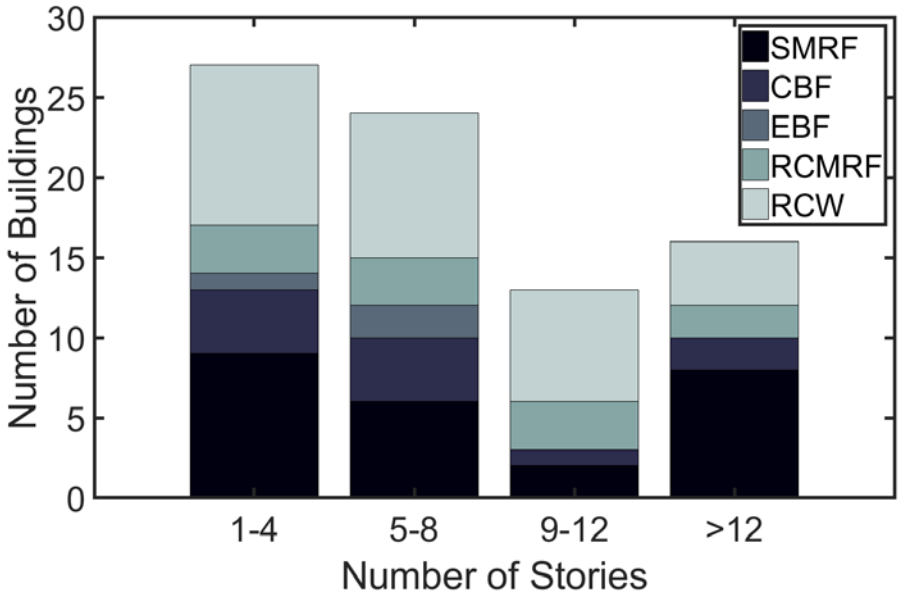
- Equivalent Modal Damping Ratio
  - Cruz, C., & Miranda, E. (2016). “Evaluation of Damping Ratios for the Seismic Analysis of Tall Buildings”.

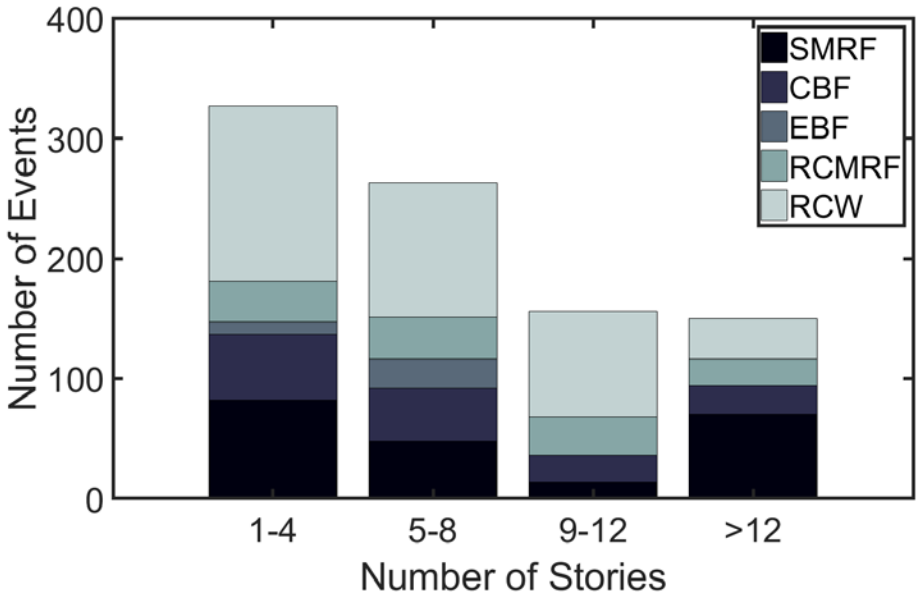




Modal Properties: @UCI

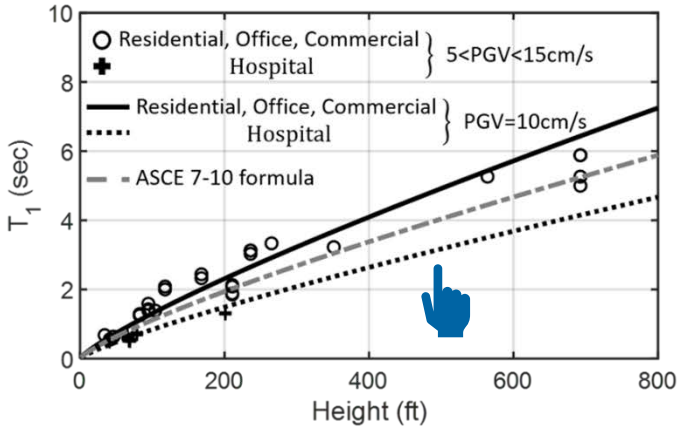
California Department of Conservation

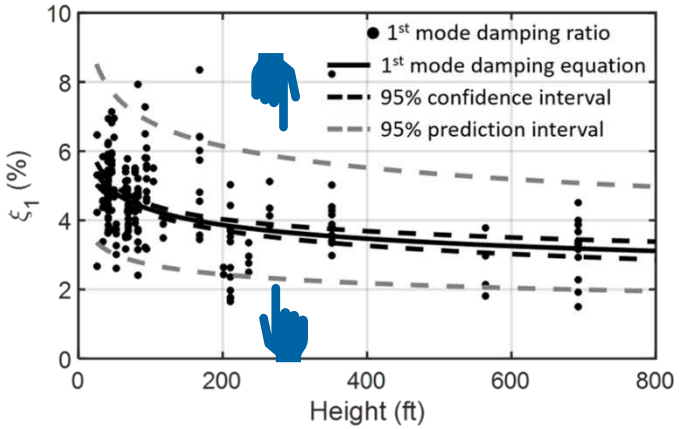




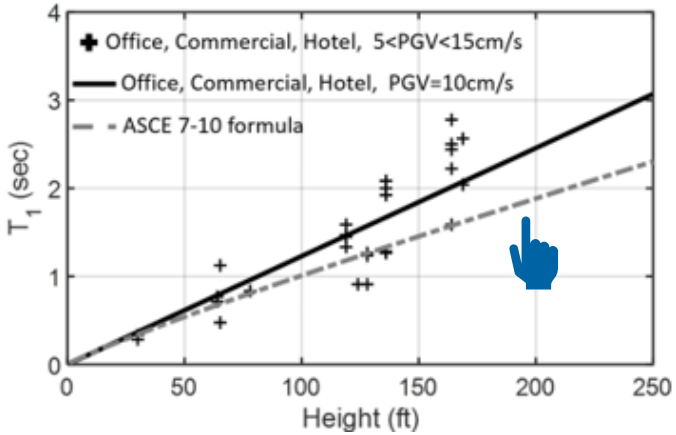
Modal Properties: @UCI

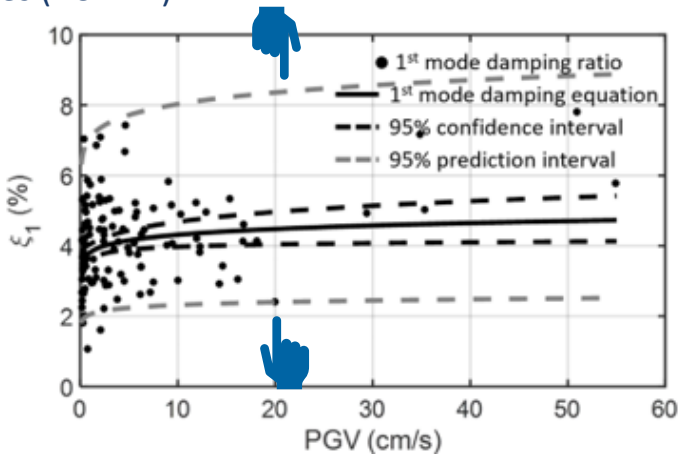
Steel Moment Resisting Frames (SMRF)





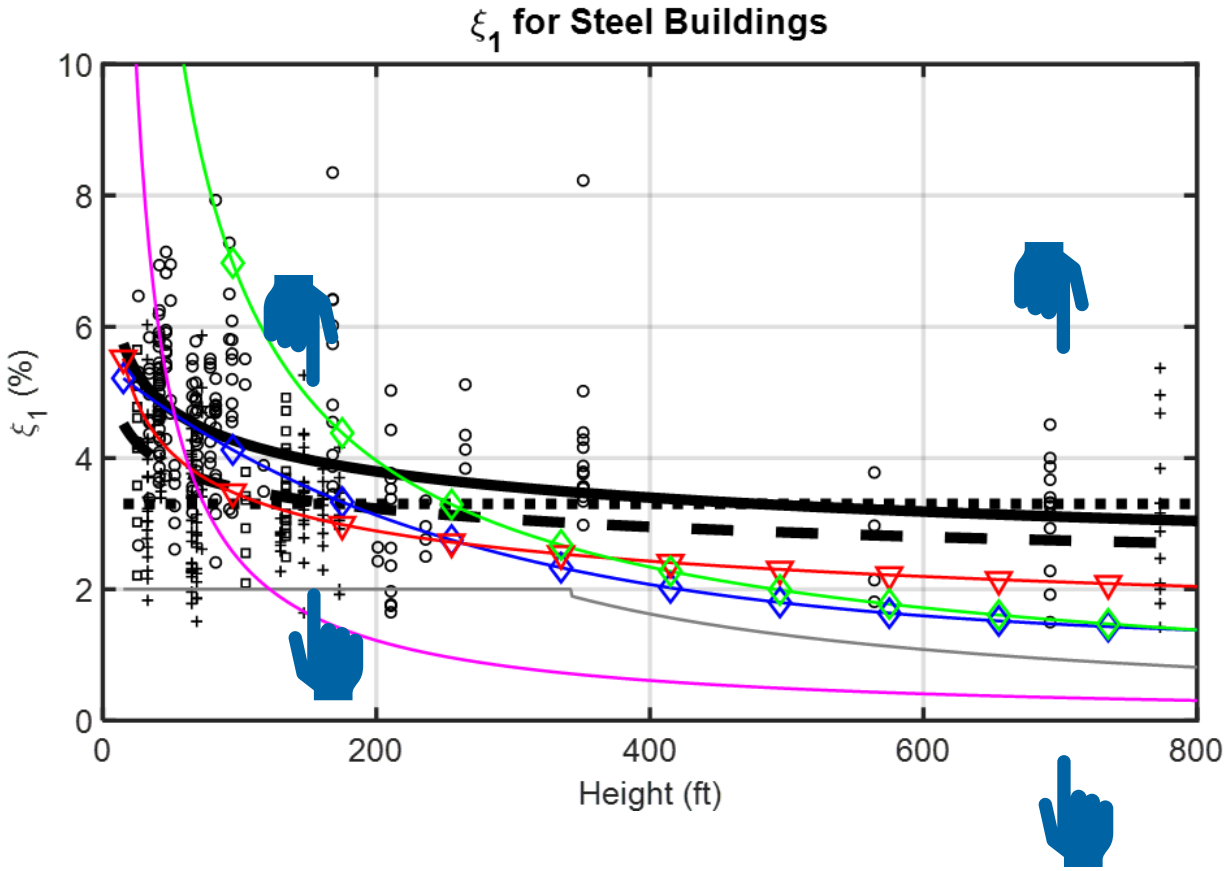
Reinforced Concrete Moment Resisting Frames (RCMRF)





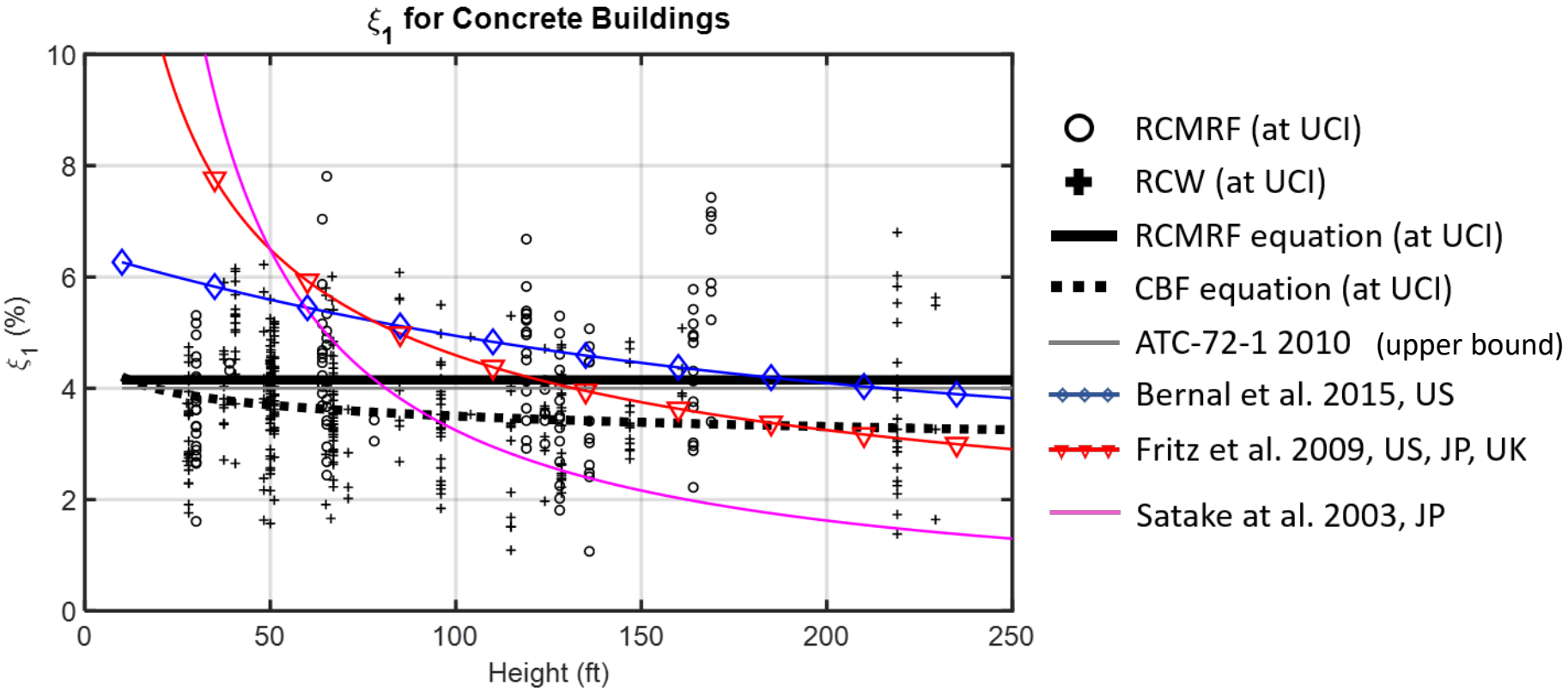
Y. Xiang, F. Naeim, and F, Zareian (2019) Evaluation of Natural Periods and Modal Damping Ratios for Seismic Design of Building Structures, *Earthquake Spectra*, (in review)

Modal Properties: Comparisons



- SMRF (at UCI)
- CBF (at UCI)
- EBF (at UCI)
- SMRF equation (at UCI)
- CBF equation (at UCI)
- EBF equation (at UCI)
- ATC-72-1 2010 (lower bound)
- Bernal et al. 2015, US
- Fritz et al. 2009, US, JP, UK
- Cruz at al. 2016, US
- Satake at al. 2003, JP

Modal Properties: Comparisons



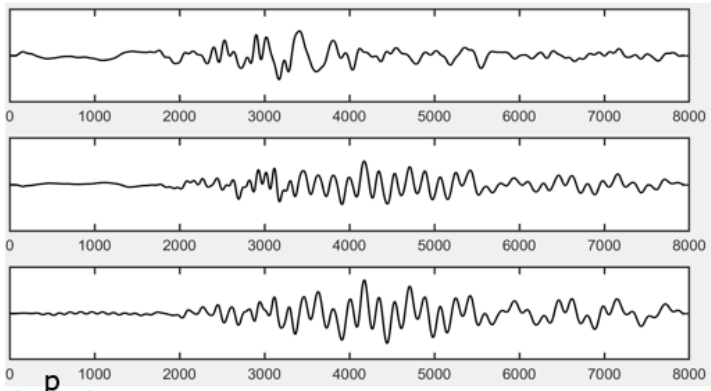
Modal Properties: @UCI

Major findings:

- ✓ Equations for T and ξ are provided for different building types.
- ✓ Damping ratio can be amplitude dependent.
- ✓ For tall buildings, the response of structures can be insensitive to first mode damping ratio.

Modal Properties: @UCI

- System Identification



p: data length

N: model order

N most significant eigen values -> *N*/2 significant modes

Hankel Matrix

row 1
row 2
row n

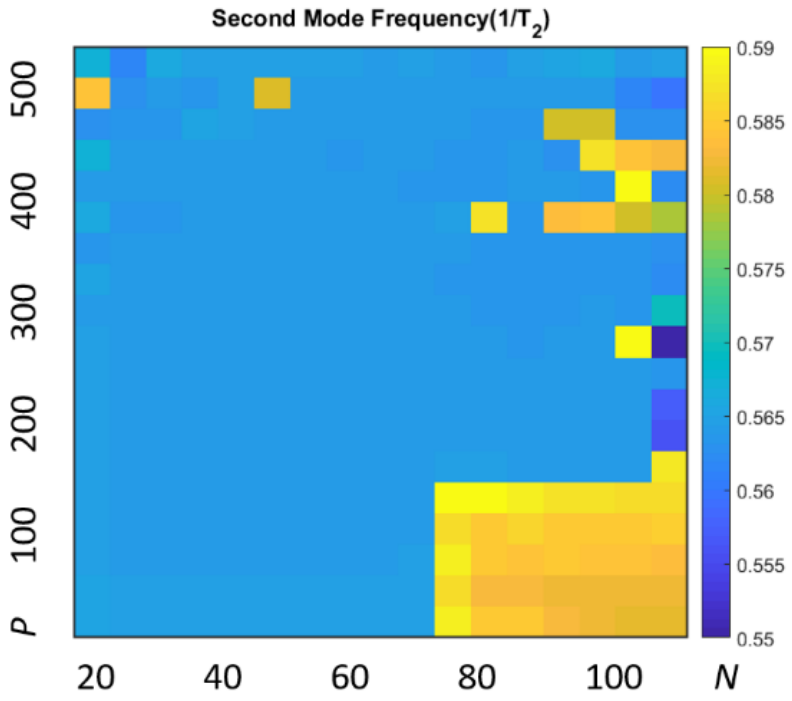
$$\begin{bmatrix} a_0 & a_1 & a_2 & \dots & \dots & a_{n-1} \\ a_1 & a_2 & & & & \vdots \\ a_2 & & & & & \vdots \\ \vdots & & & & & a_{2n-4} \\ \vdots & & & & a_{2n-4} & a_{2n-3} \\ a_{n-1} & \dots & \dots & a_{2n-4} & a_{2n-3} & a_{2n-2} \end{bmatrix}.$$

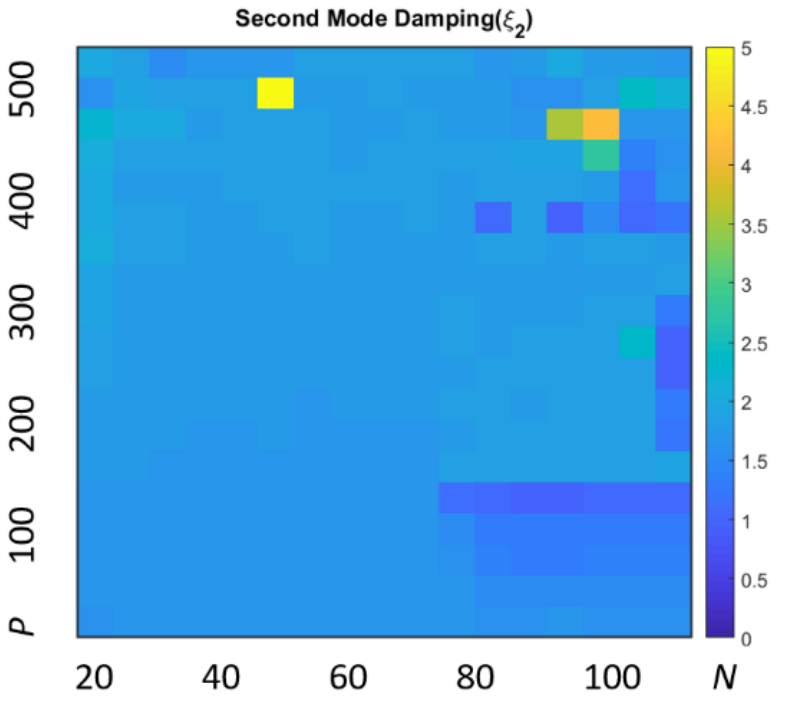
Singular Value Decomposition (SVD)

Modal Properties: @UCI

- System Identification

p: data length *N*: model order

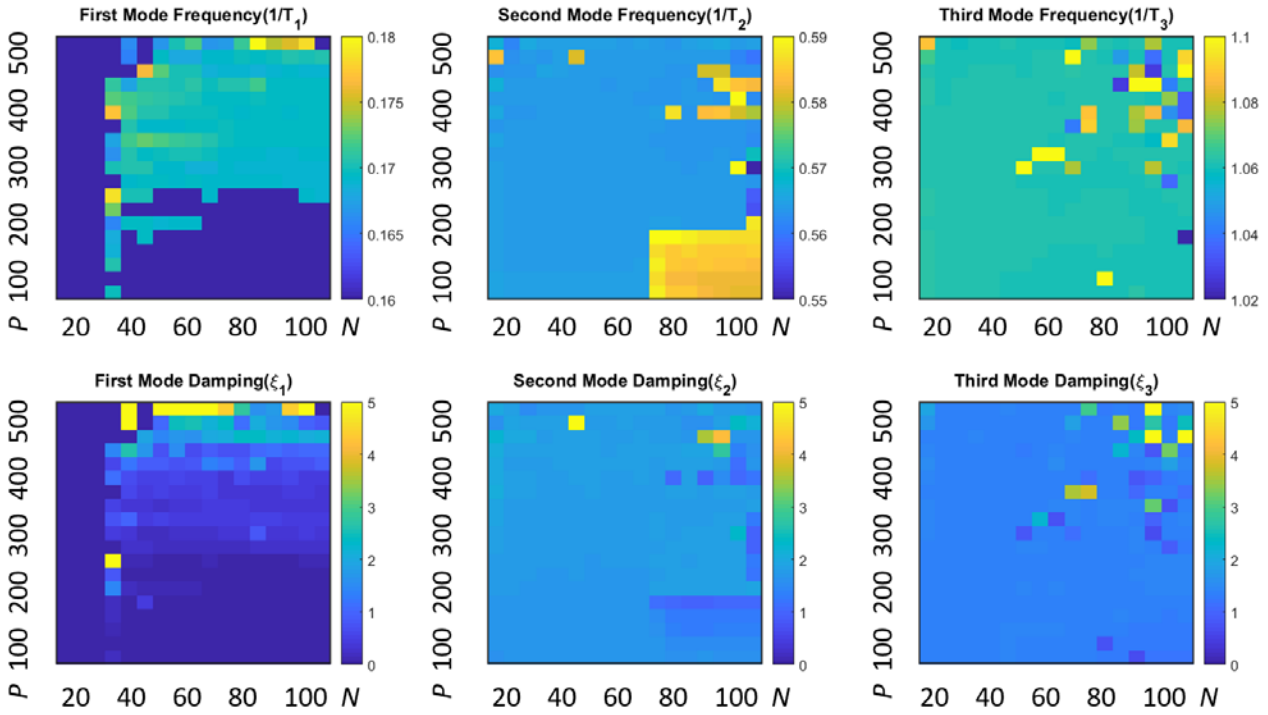




Modal Properties: @UCI

- System Identification

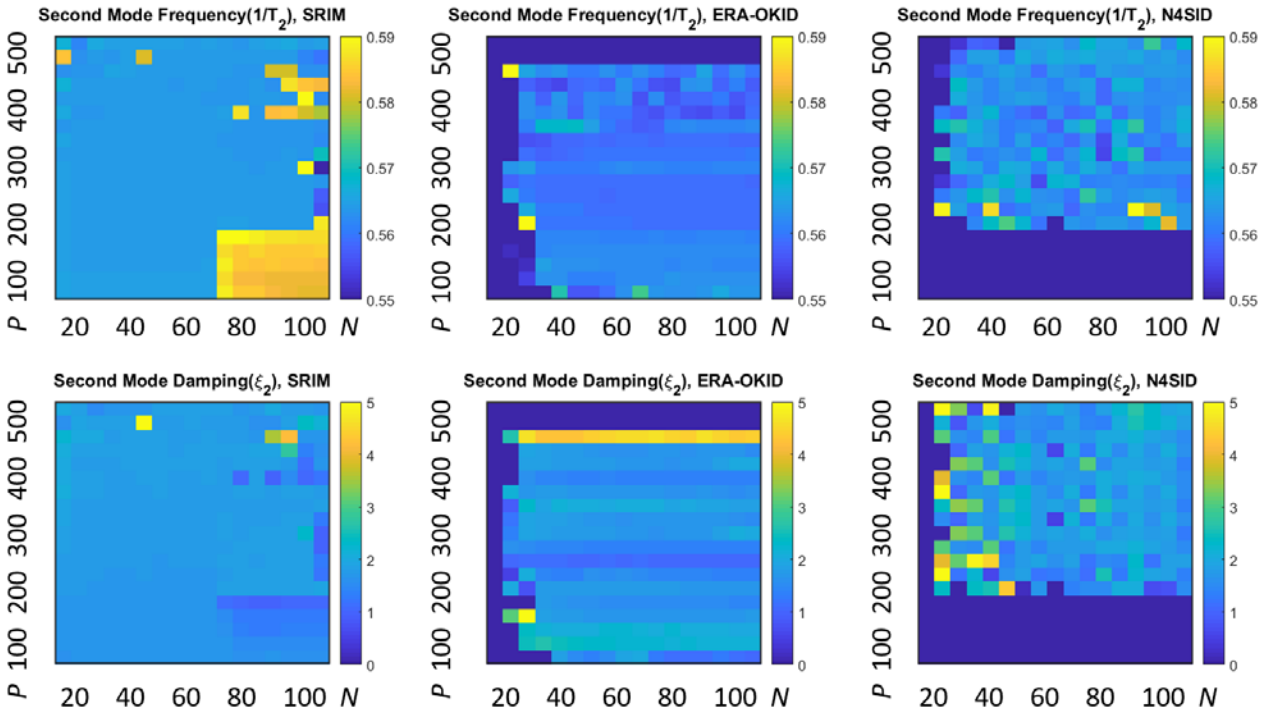
Modal Properties (first three modes) of LA-52 estimated by System ID method: SRIM



Modal Properties: @UCI

- System Identification

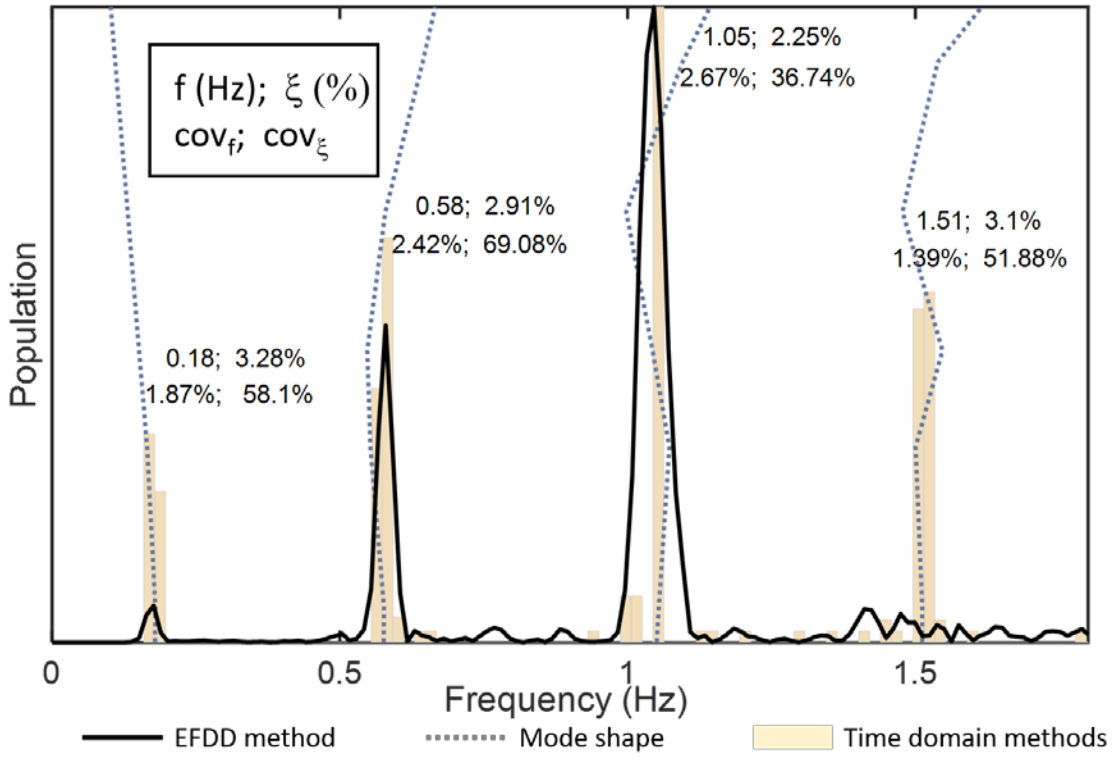
Modal Properties (2nd mode) of LA-52 estimated by three System ID methods: SRIM, ERA-OKID and N4SID



Modal Properties: @UCI

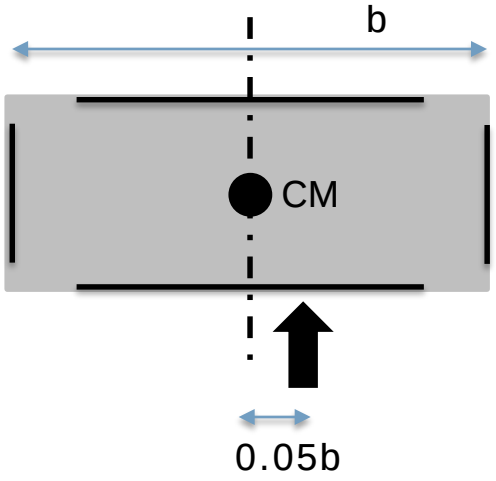
- System Identification

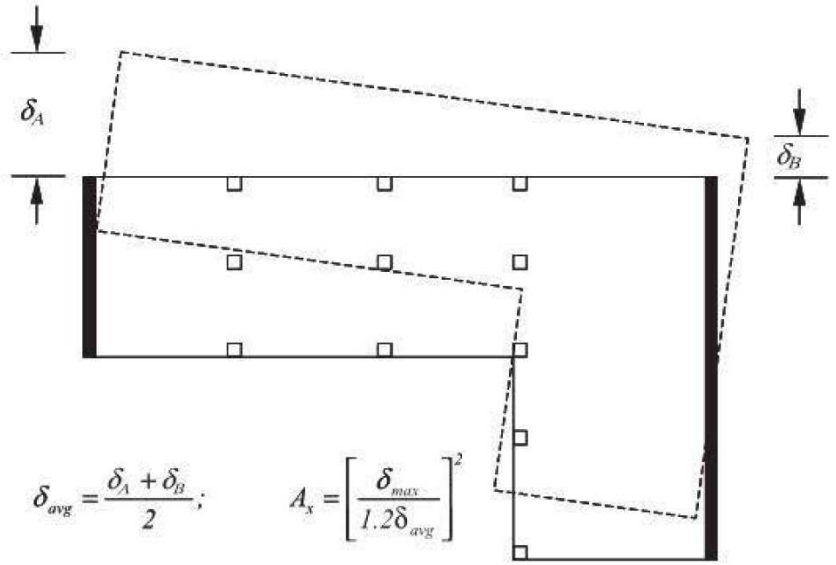
A combined method for estimating modal properties using both time-domain methods and frequency domain method (EFDD)



Accidental Torsion

- Accidental Torsion
  - ASCE 7-10 says: "…accidental torsional moments caused by assumed displacement of the center of mass each way from its actual location by a distance equal to **5 percent** of the dimension of the structure perpendicular to the direction of the applied forces."



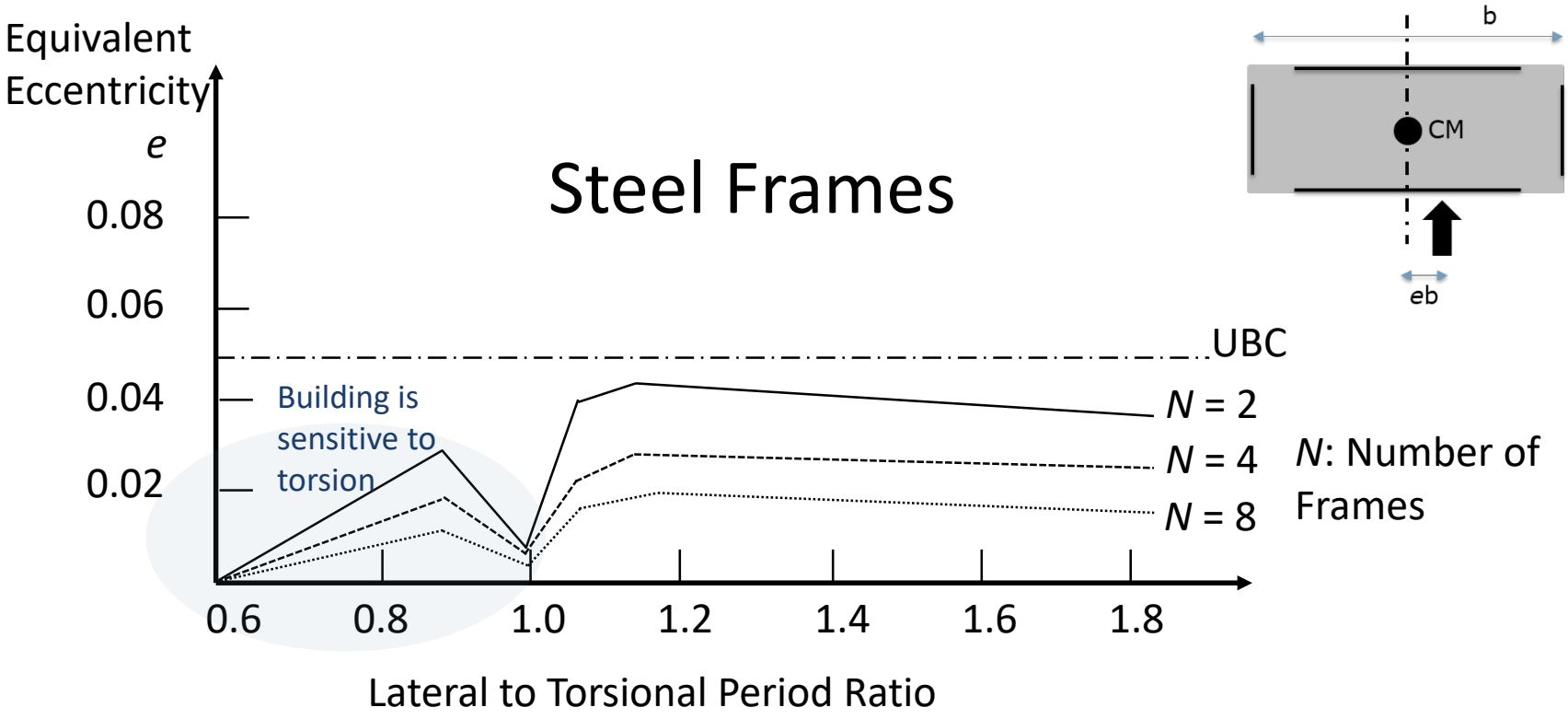


$1.4 > \delta_A/\delta_{avg} > 1.2$ Type 1a

$\delta_A/\delta_{avg} > 1.4$ Type 1b

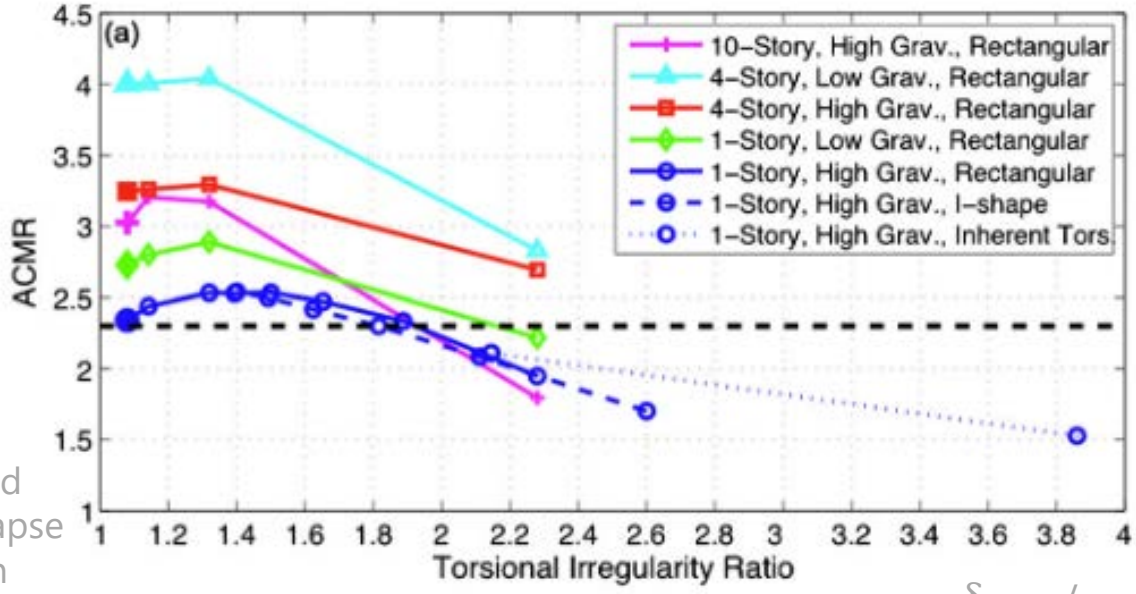
Accidental Torsion: previous research

- Accidental Torsion
  - De la Llera, J.C., Chopra, A.K. (1994). "Accidental Torsion in Buildings Due To Stiffness Uncertainty".



Accidental Torsion: previous research

- Accidental Torsion
  - DeBock *et al*. (2014). "Importance of seismic design accidental torsion requirements for building collapse capacity".



ACMR: Adjusted Collapse Marginal Ratio

The ratio of the median ground motion intensity at which collapse occurs, to *MCE* ground motion intensity

$$TIR = \delta_{max} / \delta_{avg}$$

"accidental torsion provisions are not necessary for seismic design of buildings without excessive torsional flexibility or asymmetry."

Accidental Torsion: @UCI

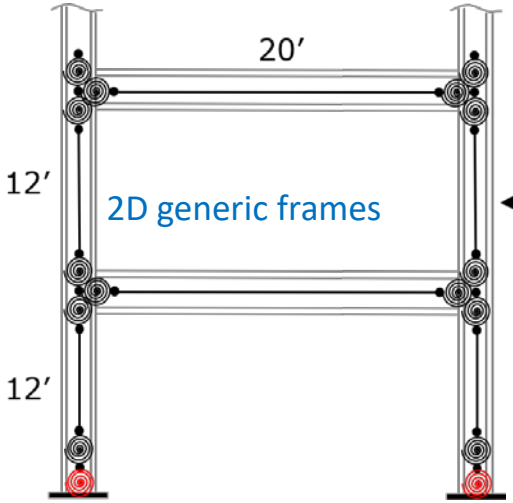
California Department of Conservation

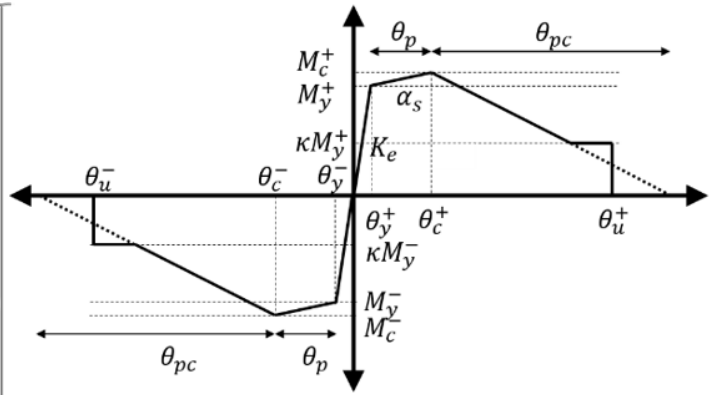
Selected buildings from CSMIP database

Building ID	*Number of stories*	*Plan Aspect Ratio*	*Category*
12299	4	1.8	4-story
58261	4	1.9	
24463	5	1.4	
12493	4	1.7	
24571	9	2.5	8-story
24386	7	2.8	
23481	7	1.5	
24249	8	2.3	
57357, x-dir	13	1.0	12-story
57357, y-dir	13	1.0	
58354	13	1.0	
24322	13	2.6	

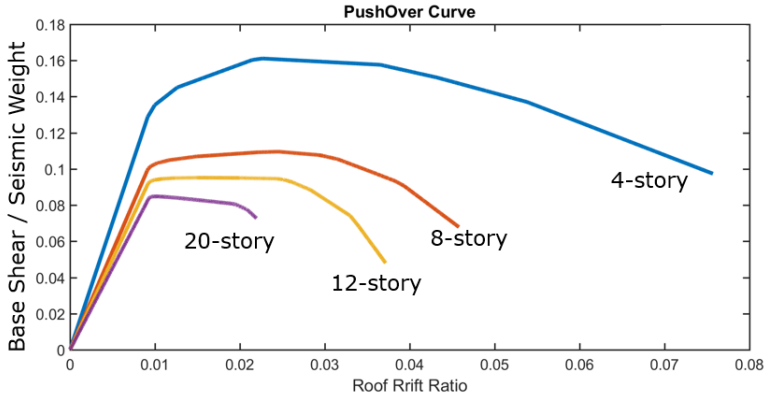
Accidental Torsion: @UCI

- Assessment of accidental torsion: Simulations vs. Instrumented data

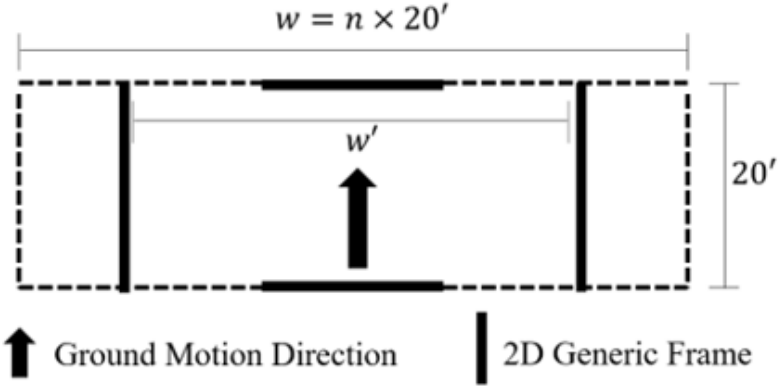




M_c/M_y	θ_p	θ_{pc}	κ	θ_u
1.1	0.03	0.2	0.4	0.2

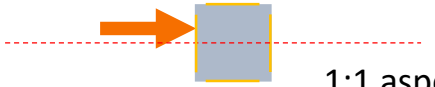


3D frames

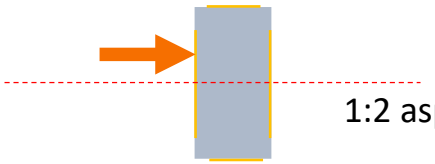


Ω:Lateral to Torsional Period Ratio

Accidental Torsion: @UCI



1:1 aspect ratio

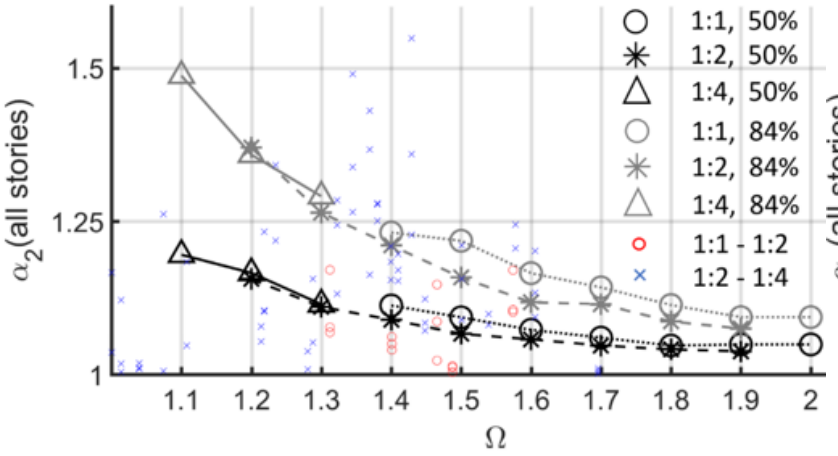


1:2 aspect ratio

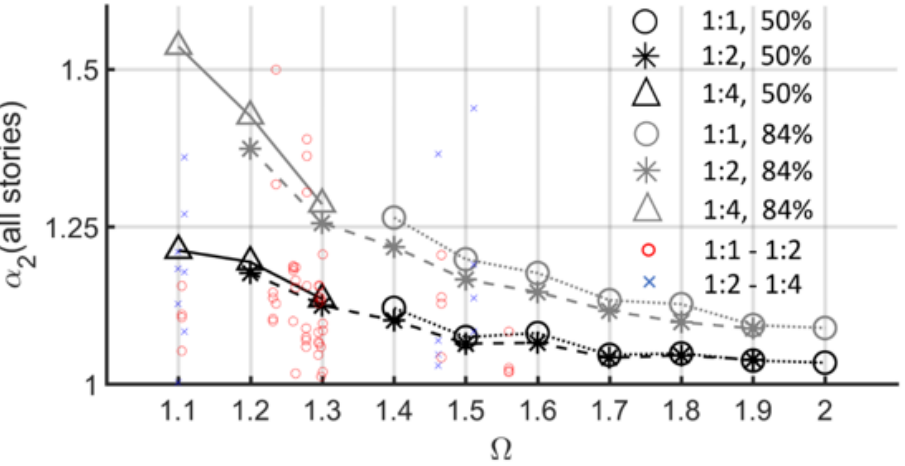
α_2:Displacement Amplification Factor

$$\alpha_2 = \frac{\max(\delta_{rot} + \delta_{tran})}{\max(\delta_{tran})}$$

Ω:Lateral to Torsional Period Ratio

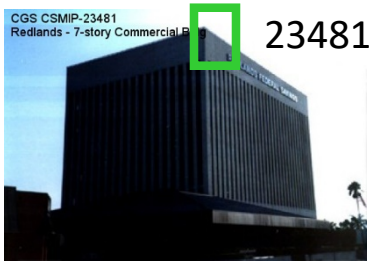


4-story buildings, 72 yrs. avg return period



8-story buildings, 72 yrs. avg return period

Accidental Torsion: @UCI (8-story bldgs.)



23481

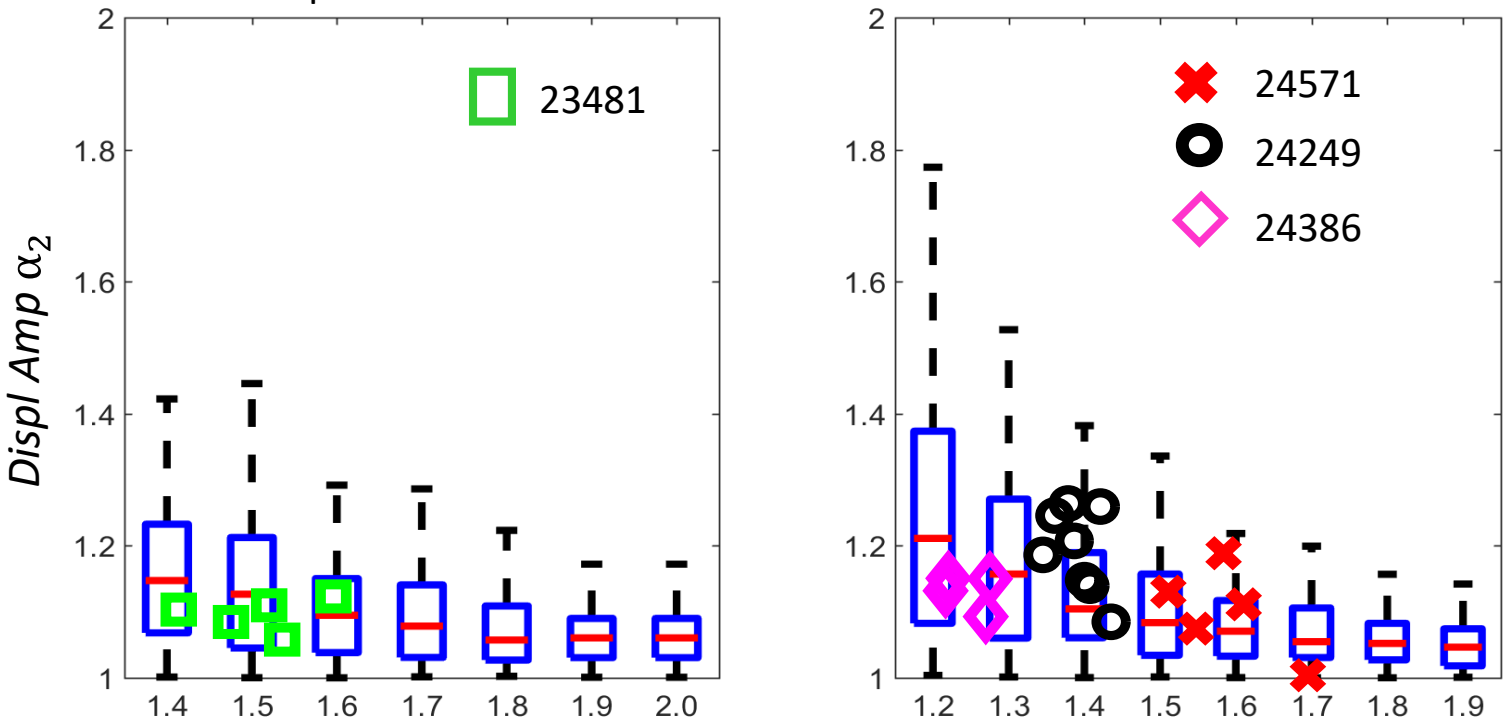
24571

24249

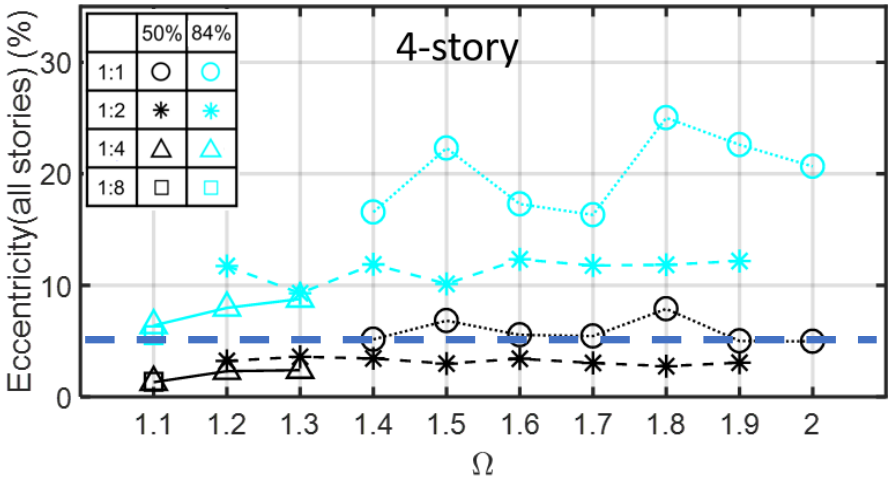
24386

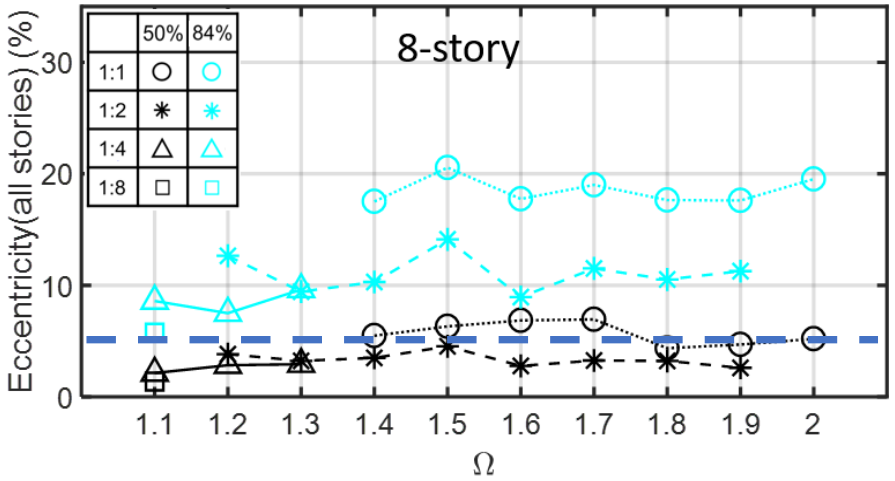
Aspect Ratio 1:1

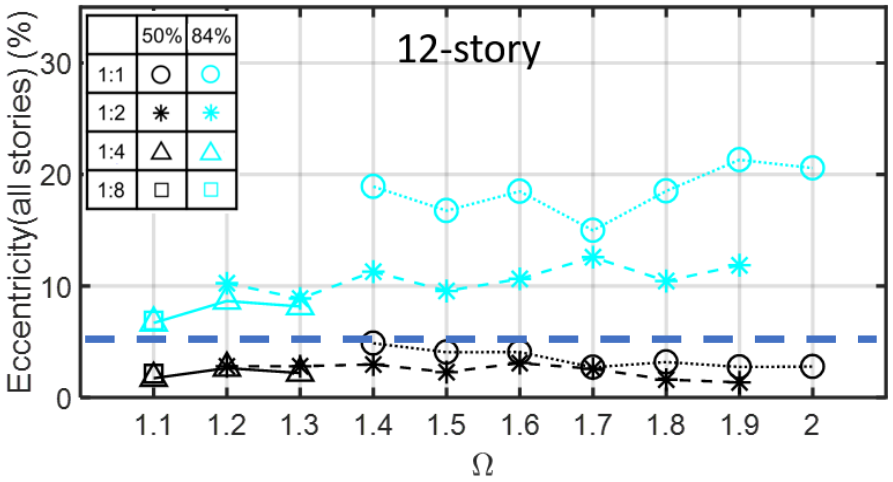
Aspect Ratio 1:2

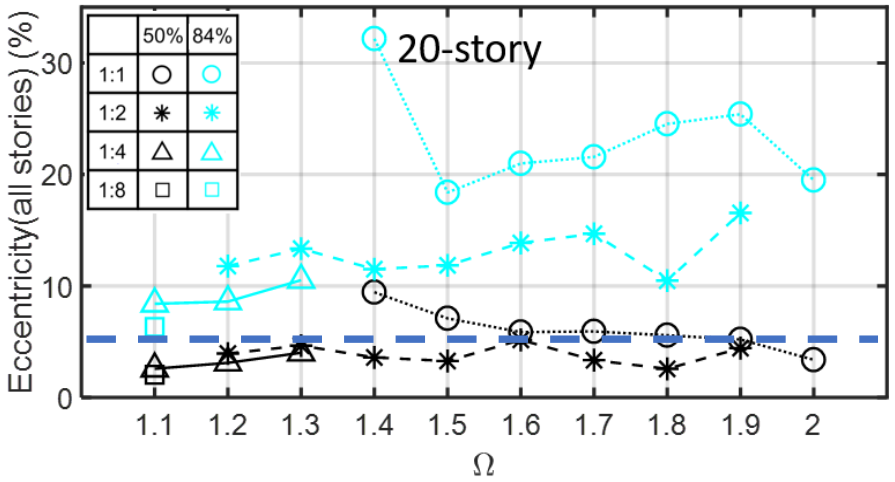


Accidental Torsion: @UCI





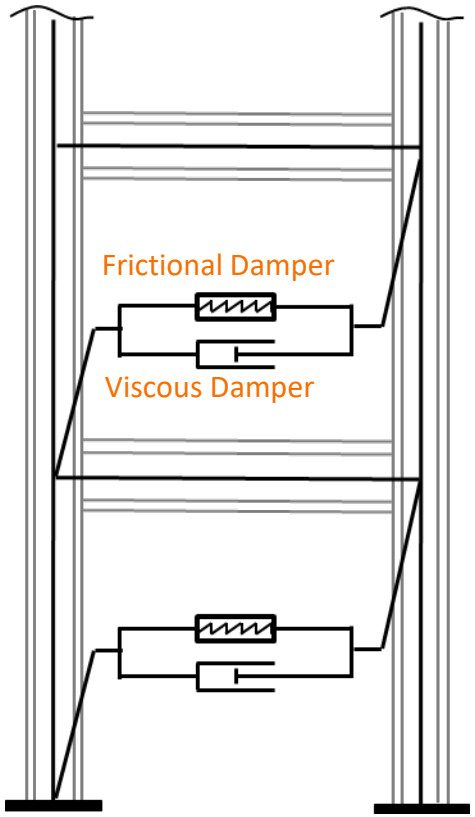


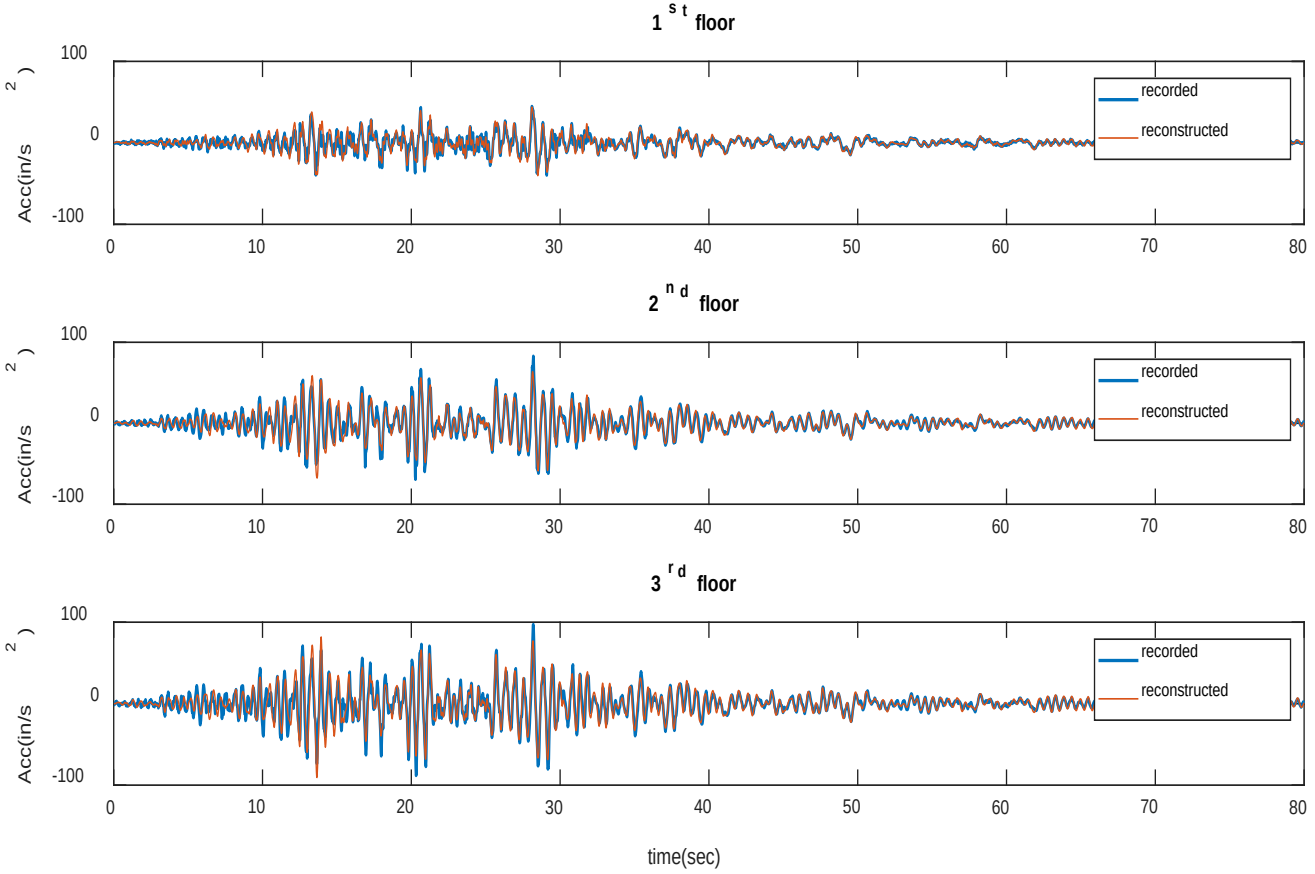


Future Directions

- A Damping Element Model for Energy Dissipation Characterization in Building Structures

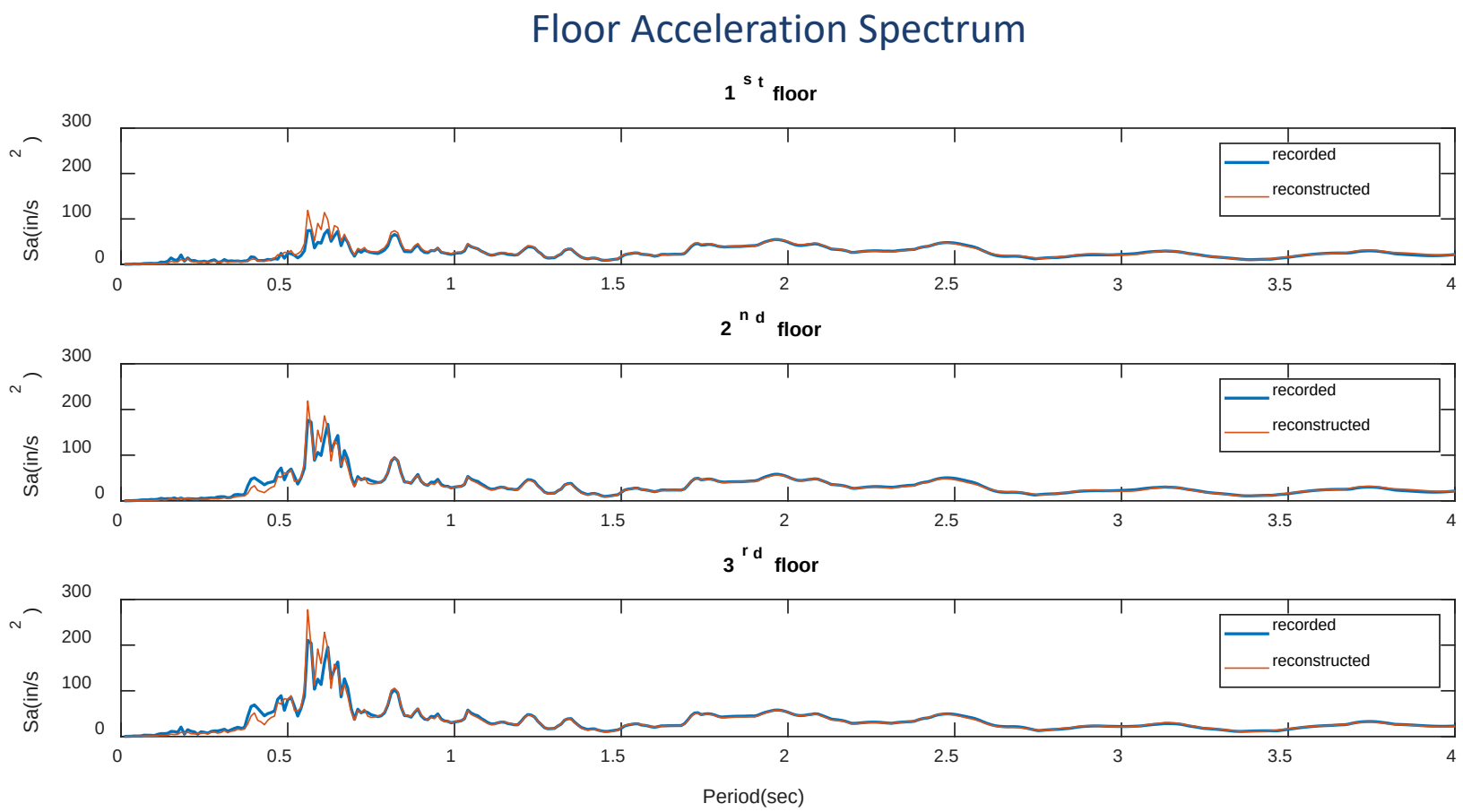
(#23516, 3-story SMRF, Landers)





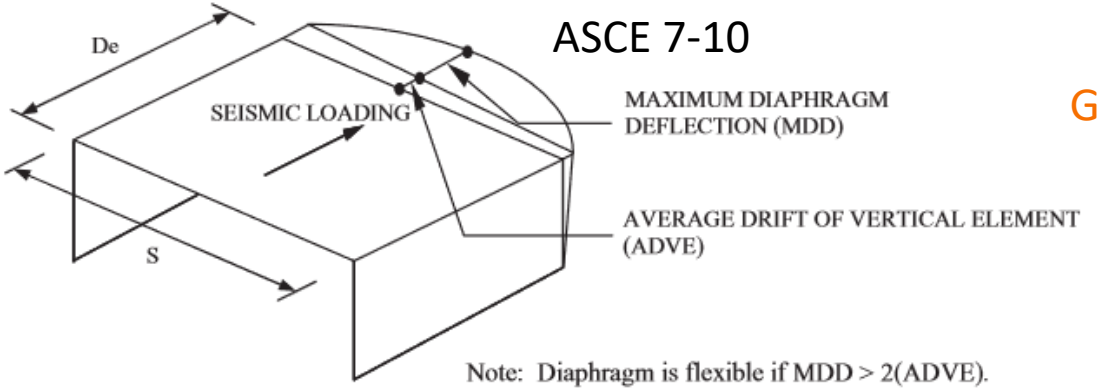
Future Directions

- A Damping Element Model for Energy Dissipation Characterization in Building Structures



Future Directions

- Assessment of Accidental Torsional Using Flexible Diaphragm Models

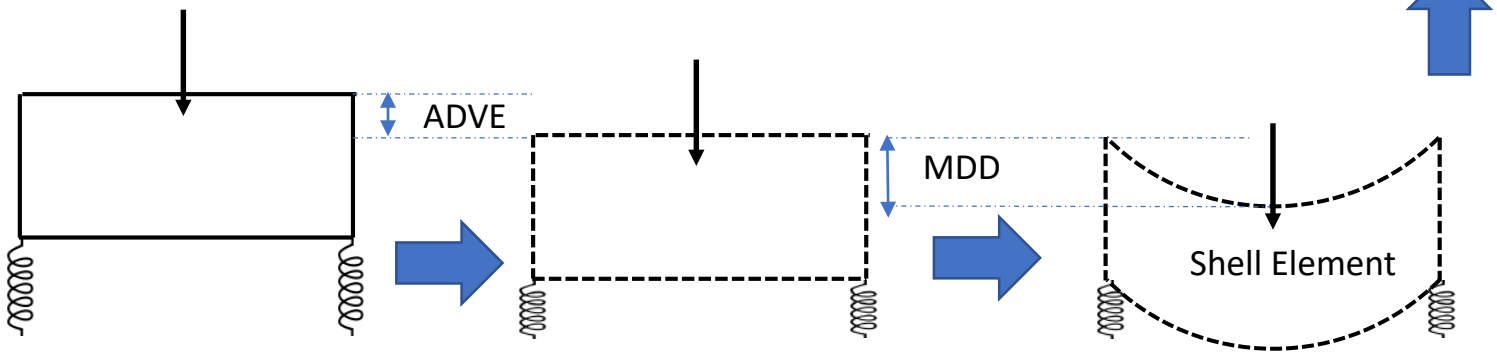


ASCE 7-10

Note: Diaphragm is flexible if MDD > 2(ADVE).

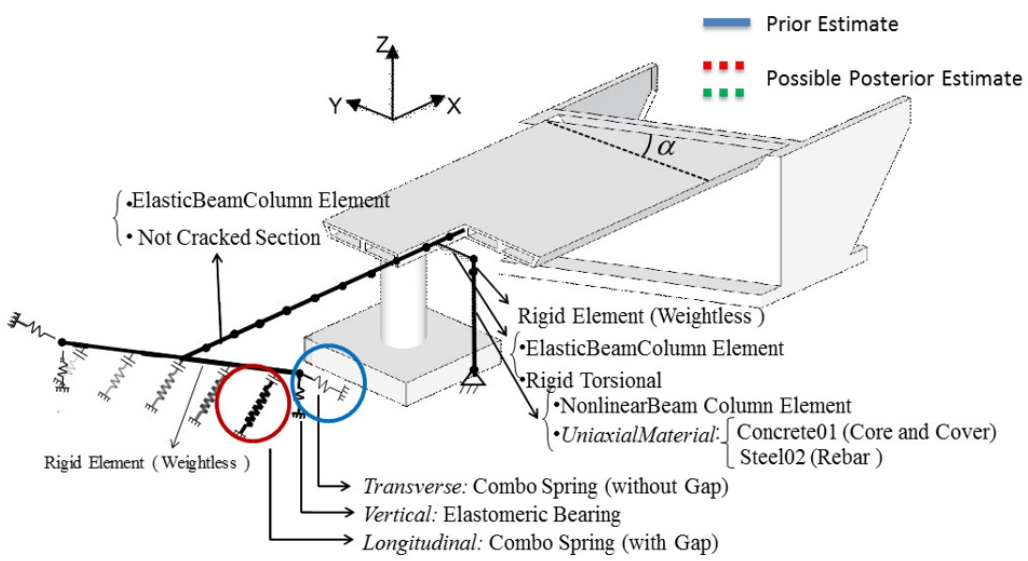
Generation of flexible diaphragm

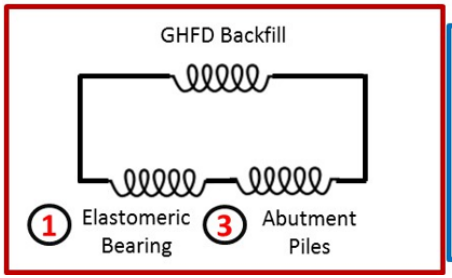
Adjust the flexibility of the shell element to meet different MDD/ADVE ratios

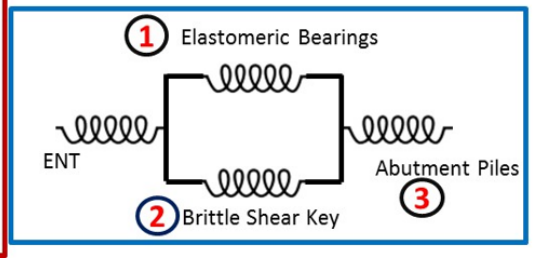


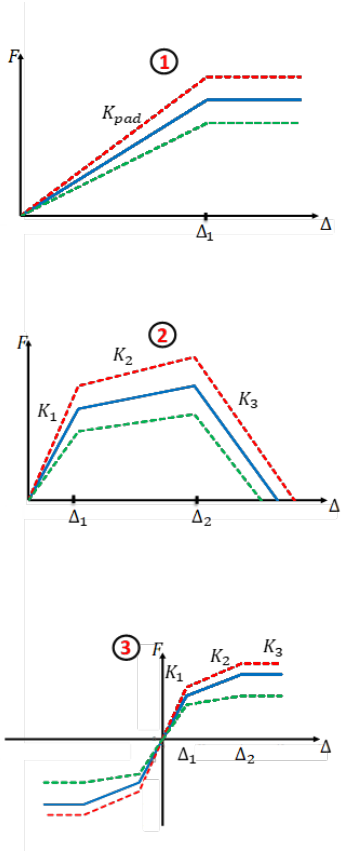
Future Directions

- Validation of Caltrans Ordinary Bridge Modeling Approach using Bayesian State and Parameter Estimation Method









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Questions