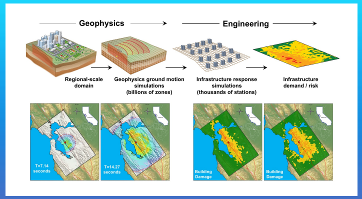

PEER International Pacific Rim Forum

June 16-17, 2021

Utilization of Synthetic Ground Motion Time-Series for Bridge Response Assessment

Farzin Zareian

UC - Irvine

Jun 16, 2021

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Credits and Acknowledgements

- Mayssa Dabaghi (AUB)

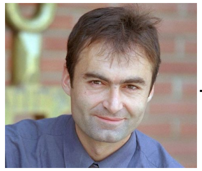
- Peyman Kaviani (Caltrans)

- Jawad Fayaz (UCL)

- Carmine Galasso (UCL)

- Huda Munjy (CSU-Fulerton)

- Sanaz Reaeian (USGS)



- Ertugrul Taciroglu (UCLA)

- Peng Zhong


SIMCITY™
BUILDIT

Intellectual Question & Industry Needs

- Need for simulated ground motions

(why)

- Generating simulated ground motion time-series

(how)

- Validating simulated ground motion time-series

(where & when)

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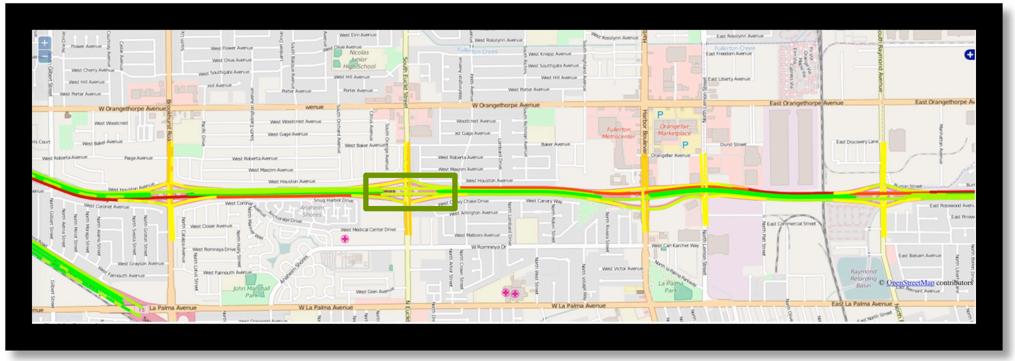
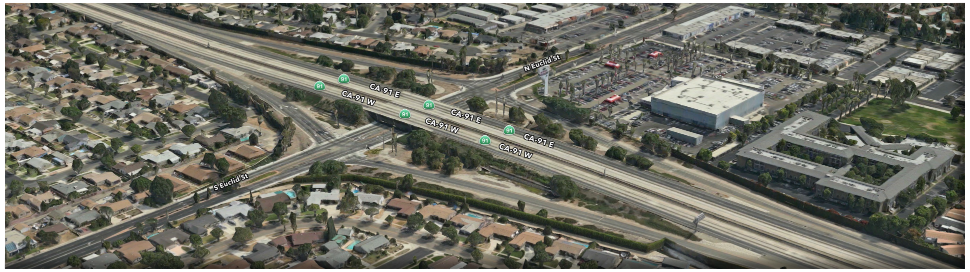
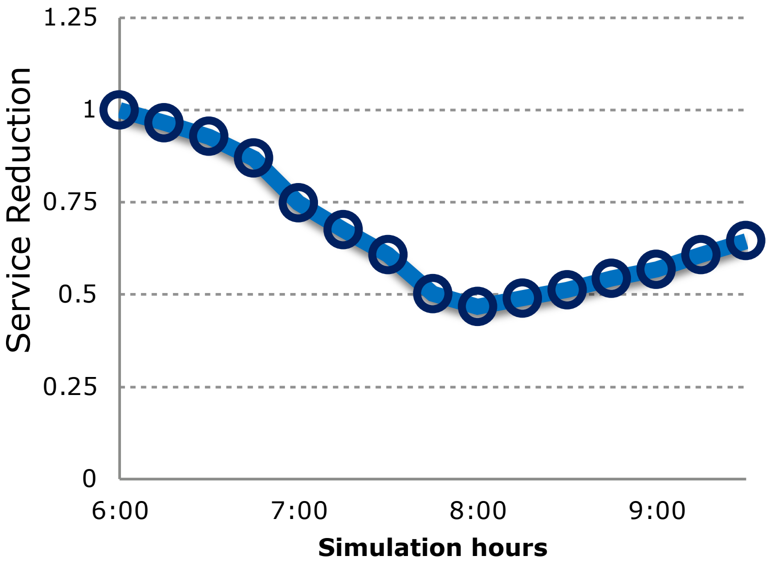
Why simulated ground motions







Kakoty P, Zareian F. Quantification of downtime in a highway network during moderate seismic events. *Proceedings of the 11th National Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

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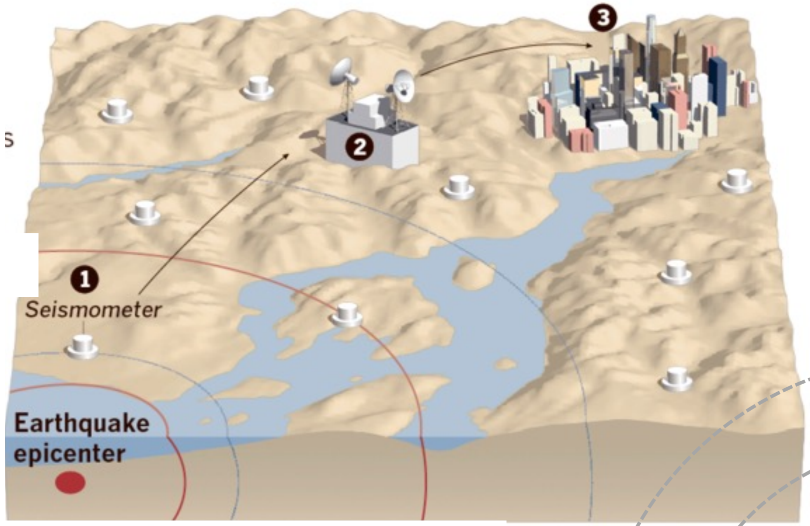
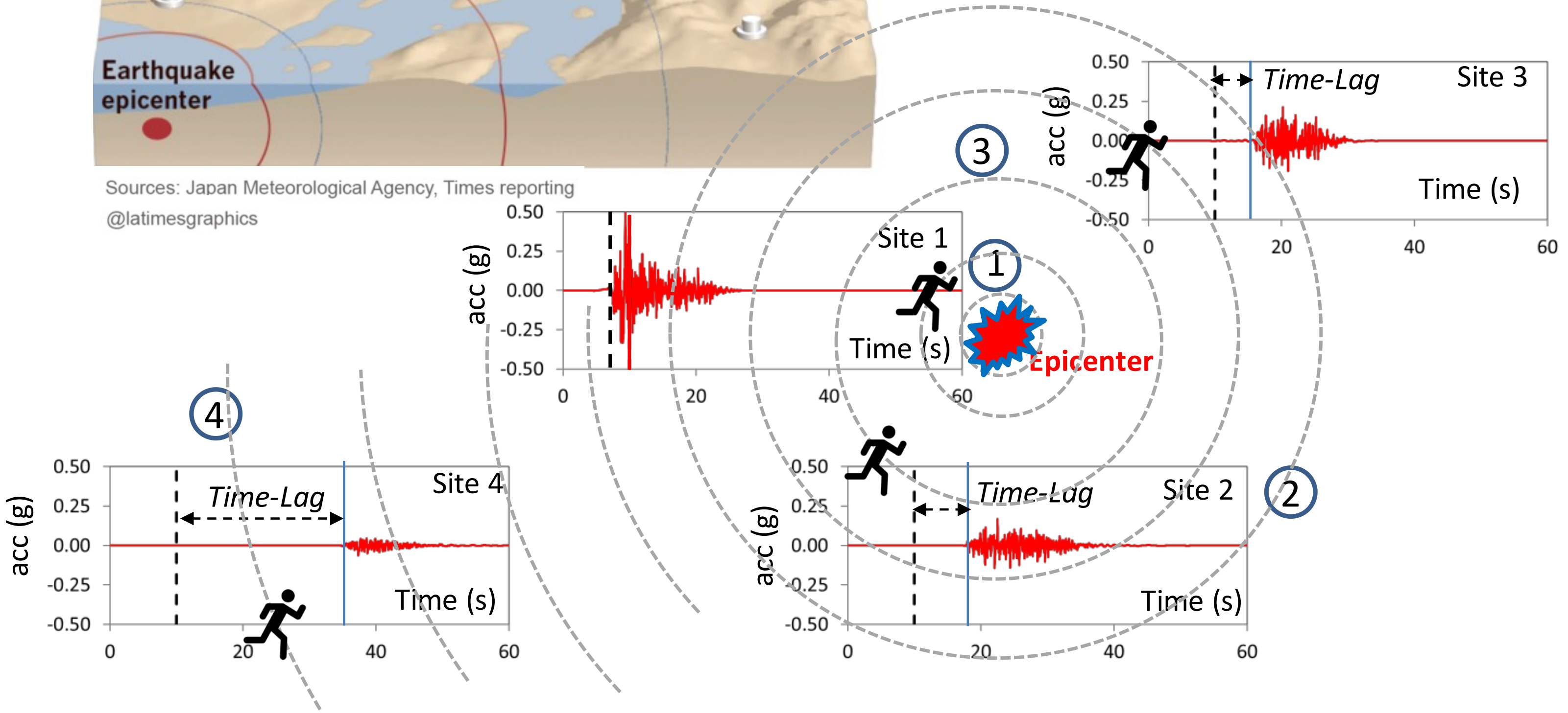
Why simulated ground m



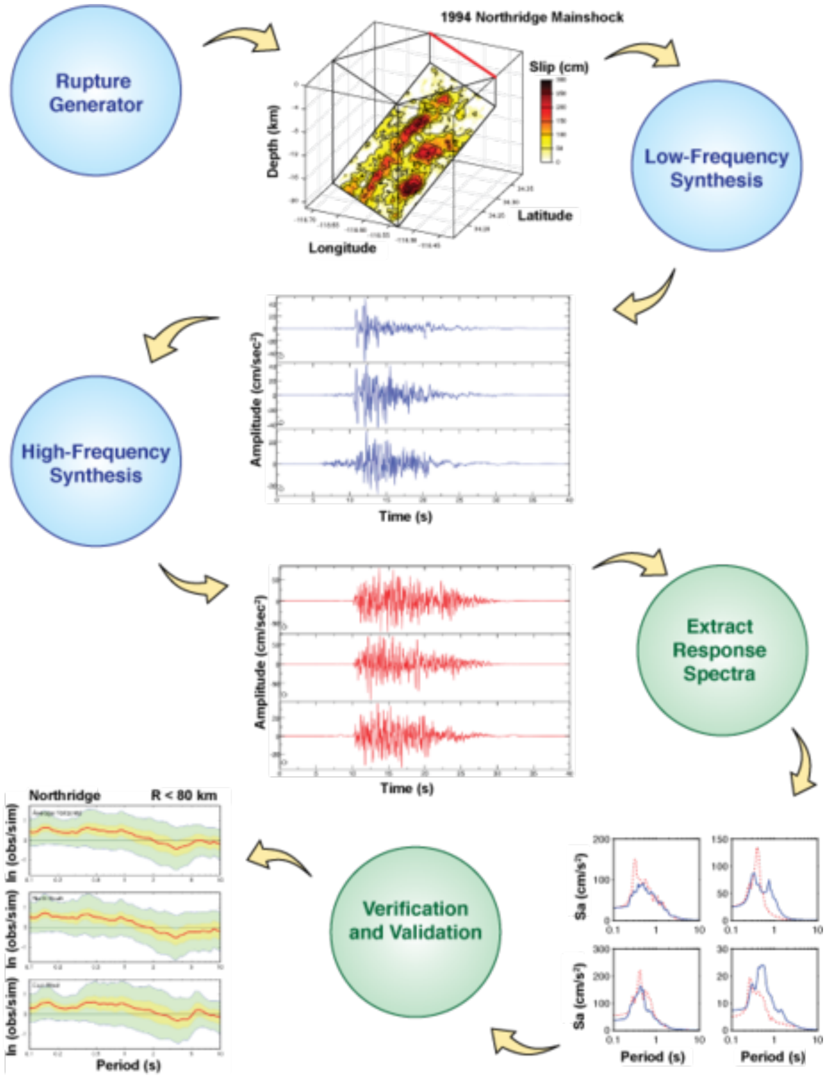
Sources: Japan Meteorological Agency, Times reporting
@latimesgraphics



R

How to generate simulated ground motions

- Site-based models
  - Stochastic
- Source-based models
  - Deterministic
  - Stochastic
  - Hybrid



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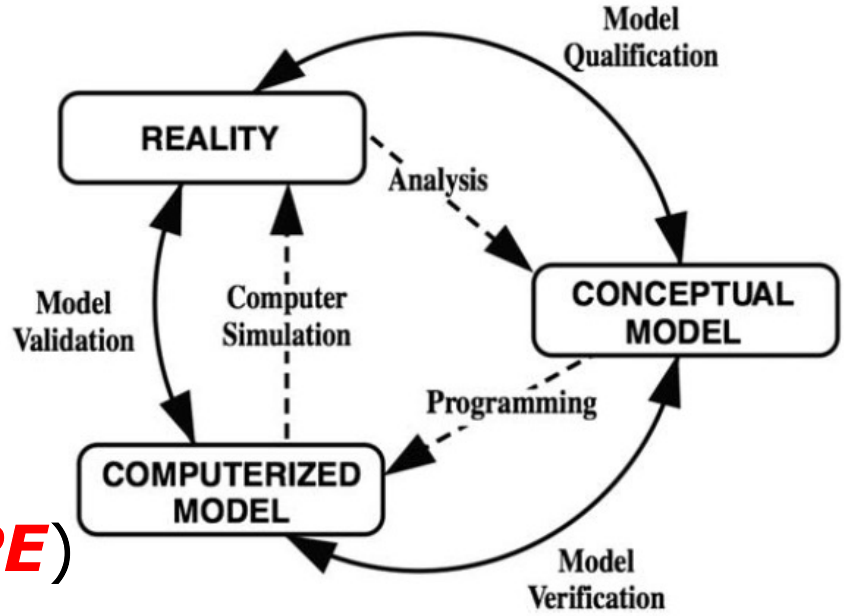
Ground Motion Simulation Validation

- **Key issues in GMSV**
  - Independent of the simulation method
  - Dependent on engineering application

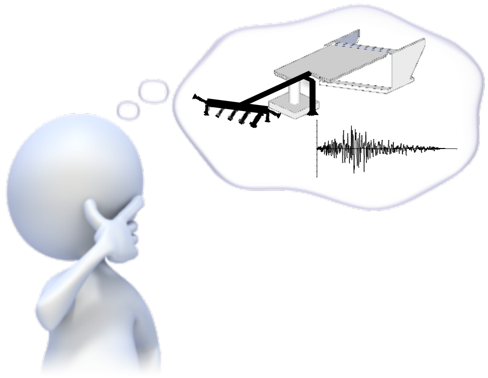
- **Key steps in GMSV**
  - Identify validation parameters. (***RZZ***)
  - Obtain an estimate of the validation parameters for recorded motions. (***GMPE***)
  - Compare validation parameters for simulated motions against their recorded estimates (***Type I, II, II Validation***).



Oberkampf W.L., DeLand S.M., Rutherford B.M., Diegert K.V., Alvin K.F., Error and uncertainty in modeling and simulation, Reliability Engineering and System Safety, 75 (2002), p. 333–357.

Ground Motion Simulation Validation

Problem Statement



- Can we develop a validation test for simulated ground motions intended for the performance assessment of ordinary bridges?
- Can we use simulated ground motions for the performance assessment of ordinary bridges?

1. Galasso, C., Kaviani, P., Tsioulou, A., Zareian, F. (2018) Validation of Ground Motion Simulations for Historical Events using Skewed Bridges. *Journal of Earthquake Engineering*.
2. Fayaz J., Azar S., Dabaghi M., and Zareian F. (2020). An Efficient Algorithm to Simulate Hazard-Targeted Site-Based Synthetic Ground Motions, *Earthquake Spectra*
3. Fayaz J., Azar S., Dabaghi M., and Zareian F. (2020). “Methodology for Validation of Simulated Ground Motions for Seismic Response Assessment: Application to Cybershake Source-based Ground Motions.” *BSSA*.
4. Fayaz J., Rezaeian S., and Zareian F., (2021). “Evaluation of Simulated Ground Motions using Probabilistic Seismic Demand Analysis: CyberShake (ver. 15.12) Simulations for Ordinary Standard Bridges.” *Earthquake Engineering and Soil Dynamics*.

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Ground Motion Simulation Validation

History of Ground Motion Simulation Validation Exercises

- Comparison between waveform shapes. (comparing wiggles)
- Comparing with IMs and EDPs of recorded data from past earthquakes.
  (IM_{rec} to IM_{sim}, EDP_{rec} to EDP_{sim})

  Type I
- Comparing IM of simulated motions to empirical ground motion models.
  (IM_{sim} to IM_{GMM}, , EDP_{rec} to EDP_{GMM})

  Type II
- Comparing EDP|IM from simulation and recorded ground motion databases. ($EDP_{sim}|IM$ to $EDP_{rec}|IM$)

  Type III

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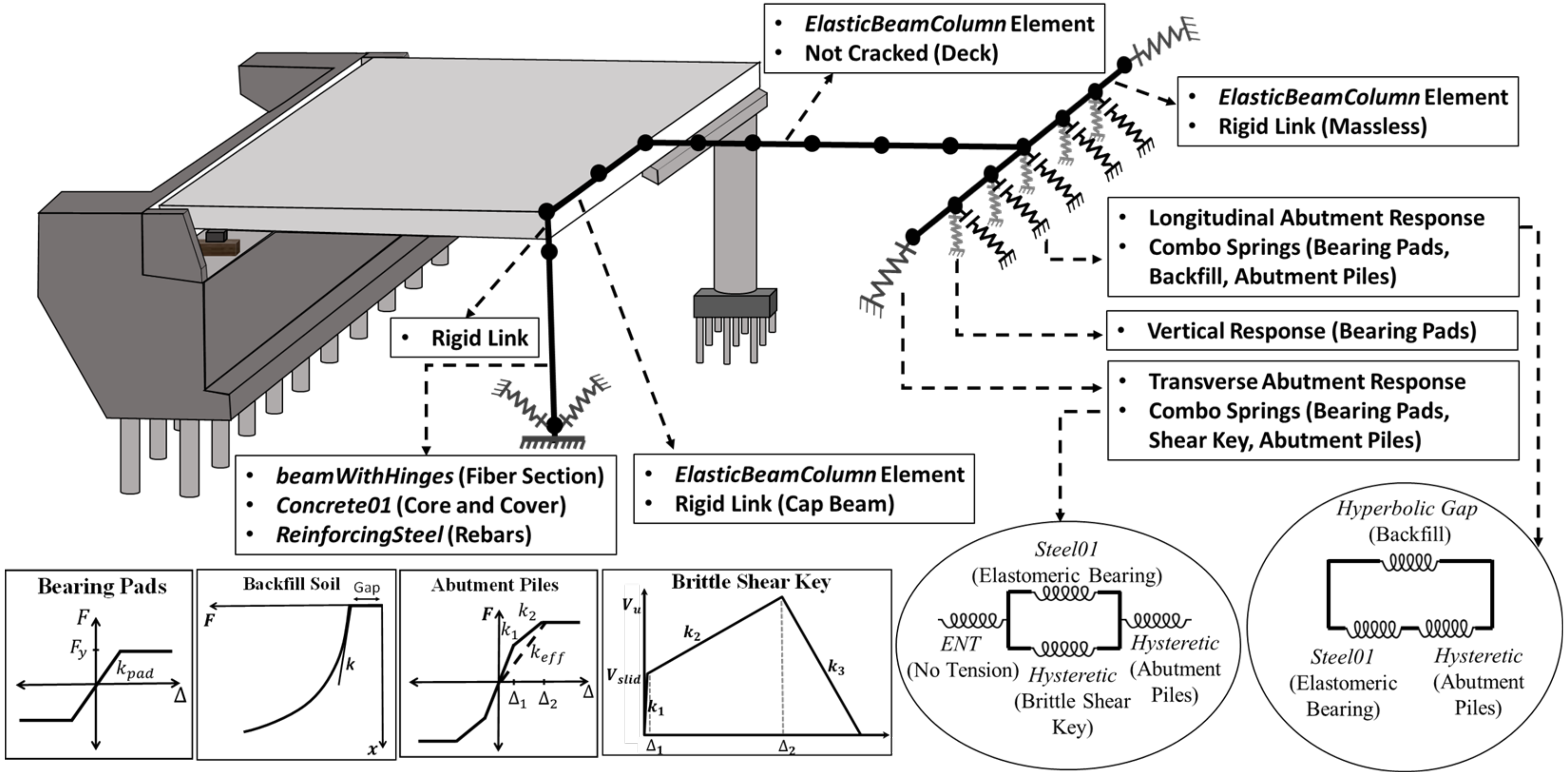
Bridge Model

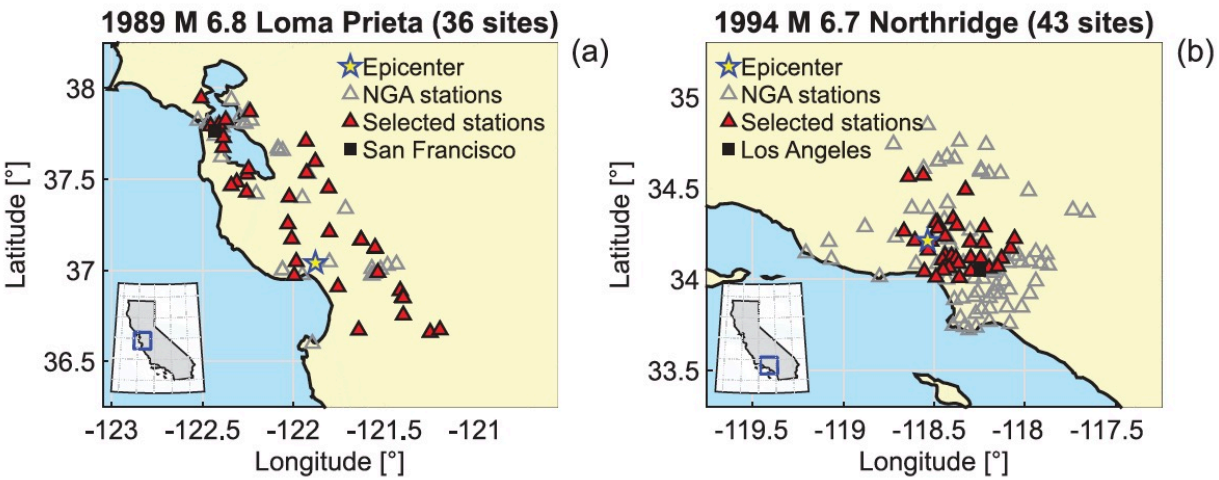


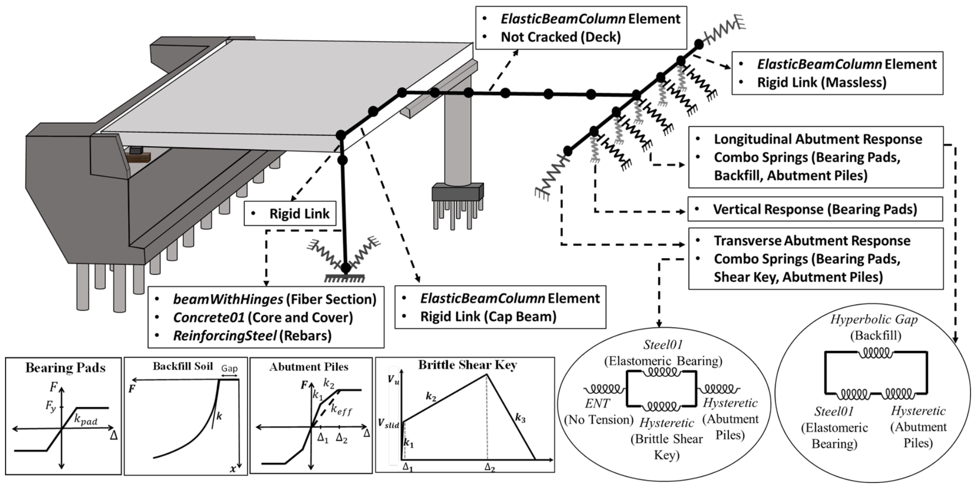
Fayaz, J., Riquelme, M., Zareian, F. (2020) Sensitivity of The Response of Box-Girder Seat-Type Bridges to the Duration of Ground Motions Arising from Crustal and Subduction Earthquakes. *Journal of Engineering Structures*

Omrani, R., Mobasher, B., Zareian, F., Taciroglu, E. (2017) Variability in The Predicted Seismic Performance of A Typical Seat-Type California Bridge Due to Epistemic Uncertainties in Its Abutment Backfill and Shear-Key Models. *Journal of Engineering Structures*,

Kaviani, P., Zareian, F., Taciroglu, E. (2012). Seismic Behavior of Reinforced Concrete Bridges with Skew-angled Seat-type Abutments. *Engineering Structures*

Type I, Ground Motion Simulation Validation





HYBRID

Bridges	Col. height	Symmetric 0°	15°	30°	45°	60°	Asymmetric 0°	15°	30°	45°	60°
Two-span, Single-col. (A)	Higher	AHS0	AHS1	AHS2	AHS3	AHS4	AHA0	AHA1	AHA2	AHA3	AHA4
	Lower	ALS0	ALS1	ALS2	ALS3	ALS4	ALA0	ALA1	ALA2	ALA3	ALA4
Two-span, Multi-col. (B)	Higher	BHS0	BHS1	BHS2	BHS3	BHS4	BHA0	BHA1	BHA2	BHA3	BHA4
	Lower	BLS0	BLS1	BLS2	BLS3	BLS4	BLA0	BLA1	BLA2	BLA3	BLA4
Three-span, Multi-col. (C)	Higher	CHS0	CHS1	CHS2	CHS3	CHS4	CHA0	CHA1	CHA2	CHA3	CHA4
	Lower	CLS0	CLS1	CLS2	CLS3	CLS4	CLA0	CLA1	CLA2	CLA3	CLA4

Galasso, C., Kaviani, P., Tsioulou, A., Zareian, F. (2018) Validation of Ground Motion Simulations for Historical Events using Skewed Bridges. *Journal of Earthquake Engineering*.

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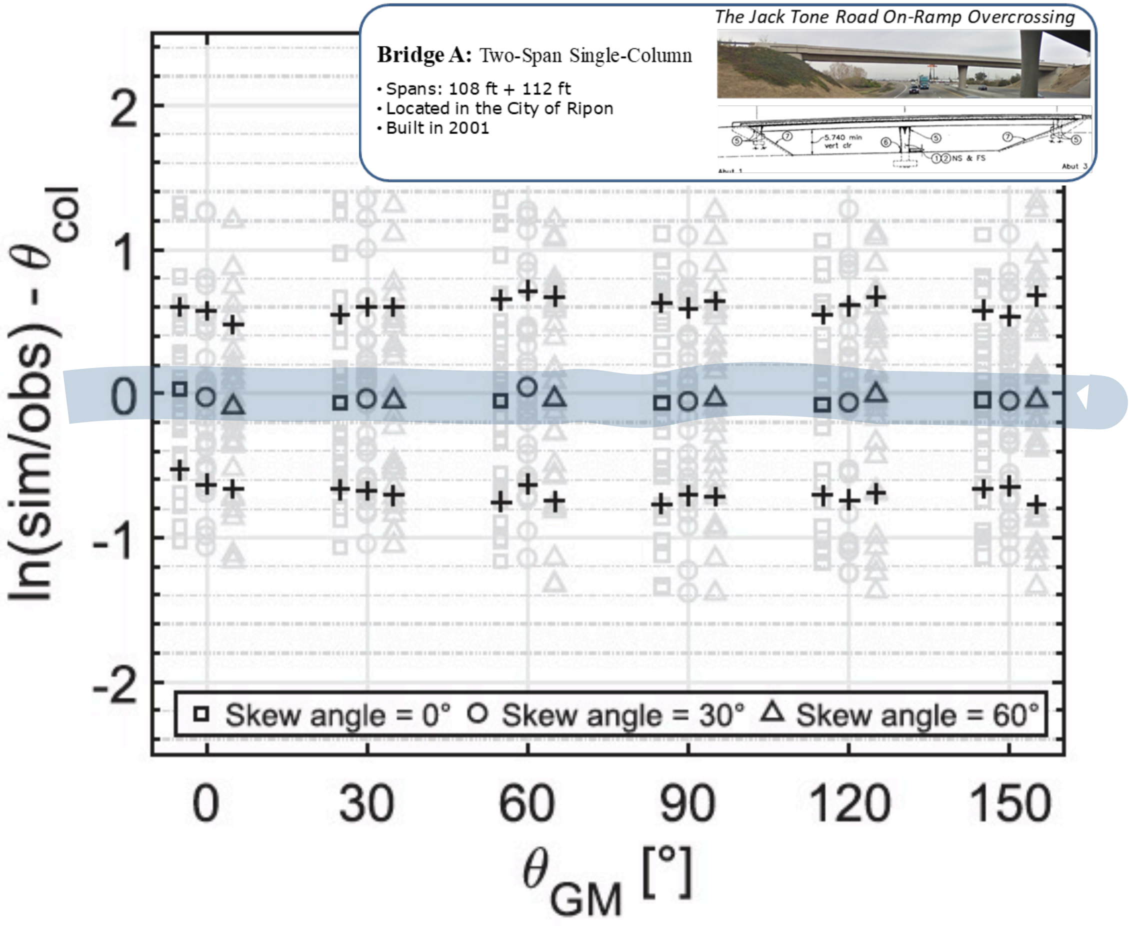
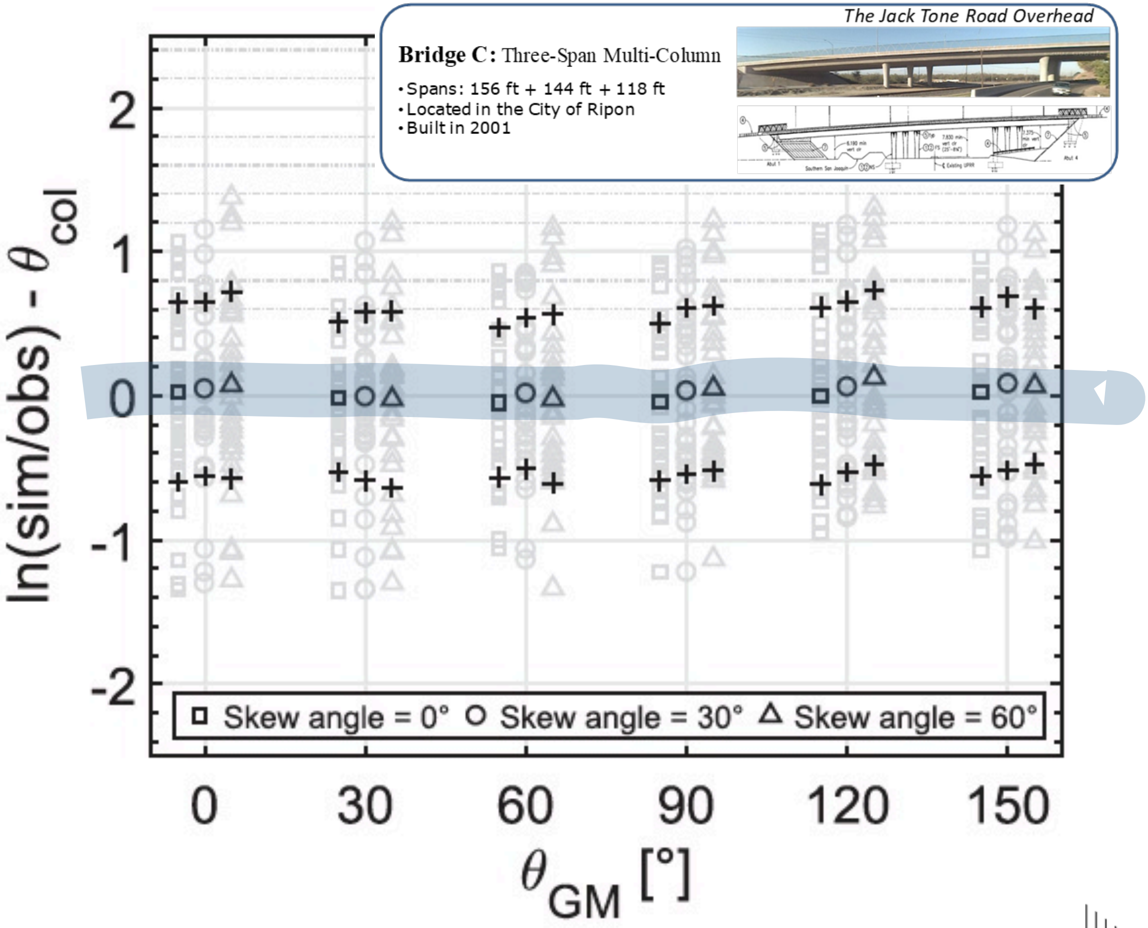
Type I, Ground Motion Simulation Validation





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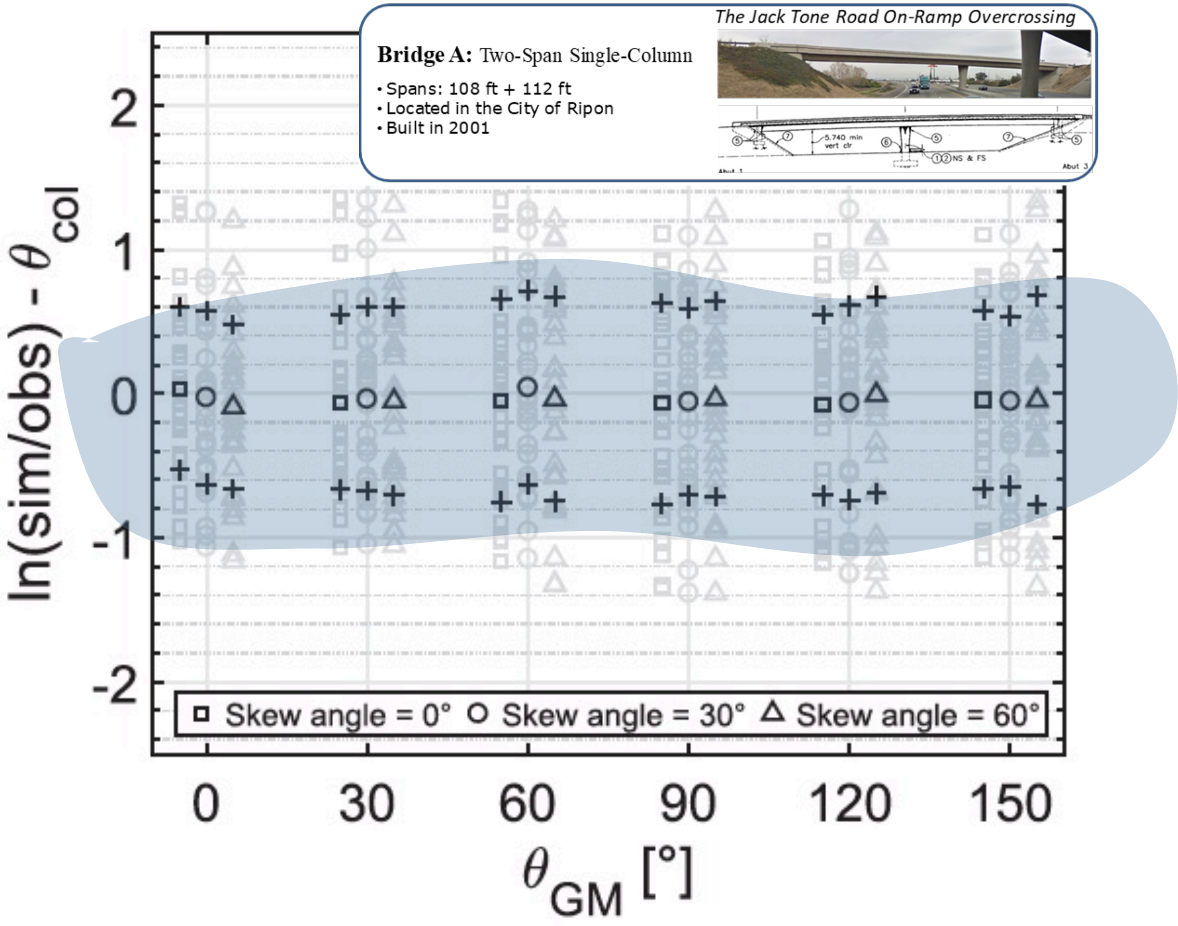

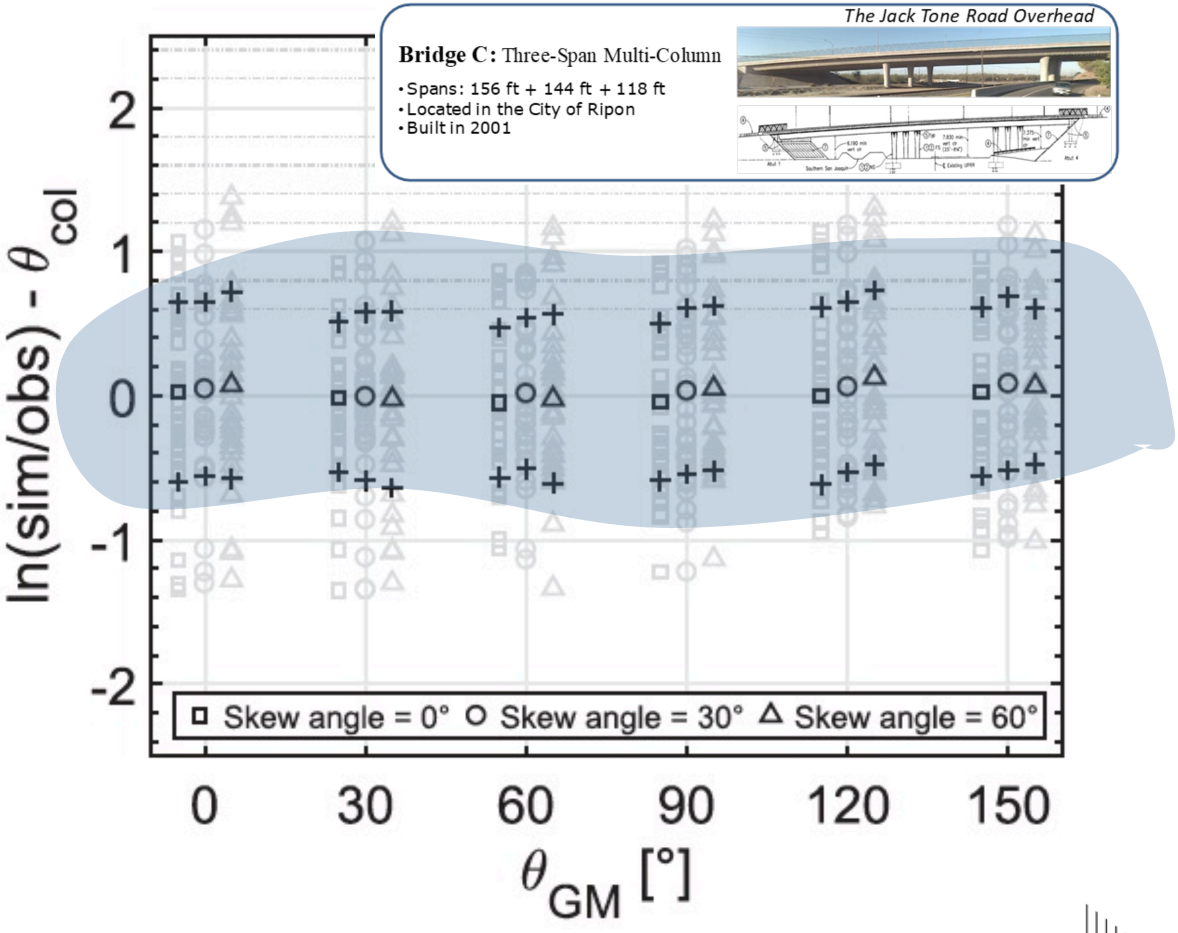

Galasso, C., Kaviani, P., Tsioulou, A., Zareian, F. (2018) Validation of Ground Motion Simulations for Historical Events using Skewed Bridges. *Journal of Earthquake Engineering*.

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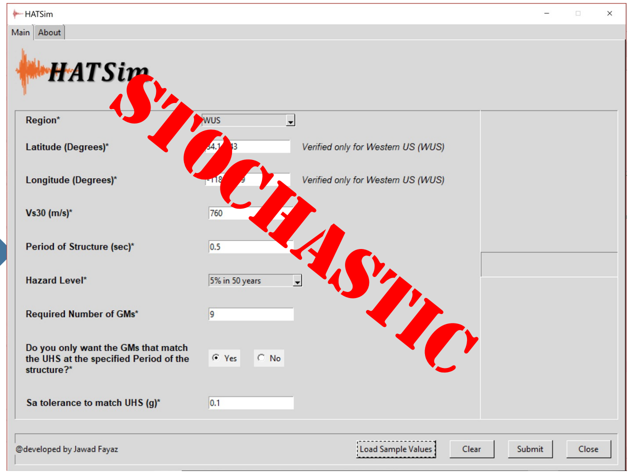
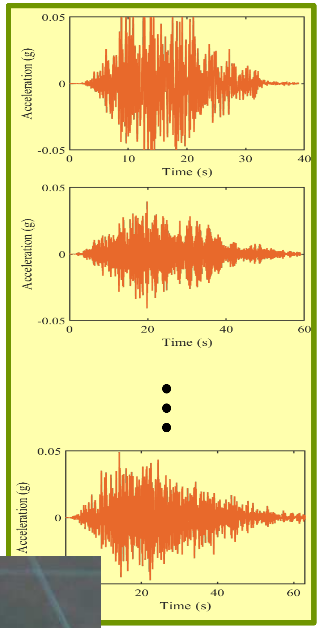
Type III, Ground Motion Simulation Validation

Bridge Location and Initial Design

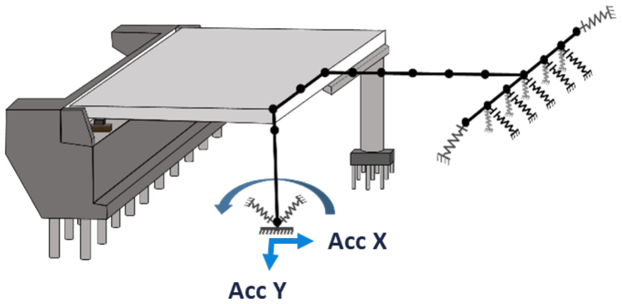
HAzard Targeted Time-Series Simulator (HATSim)



9 Bi-Directional GMs



Apply and rotate each Bi-Directional GM from $0°$ to $150°$ with increment of $30°$



For each Bi-Directional GM obtain *Rot50EDP*

Design Column drift Ratio =

$$4^{th}\ \textit{largest} \begin{Bmatrix} Rot50EDP_{GM1} \\ \vdots \\ Rot50EDP_{GM9} \end{Bmatrix}$$

Target Ductility Demand (μ_D)

Single Column Bent: $\mu_D \leq 4$
Multi-Column Bents: $\mu_D \leq 5$
(Return Period - 975 years)

Fayaz J., Azar S., Dabaghi M., and Zareian F. (2020). An ... Synthetic Ground Motions, *Earthquake Spectra*

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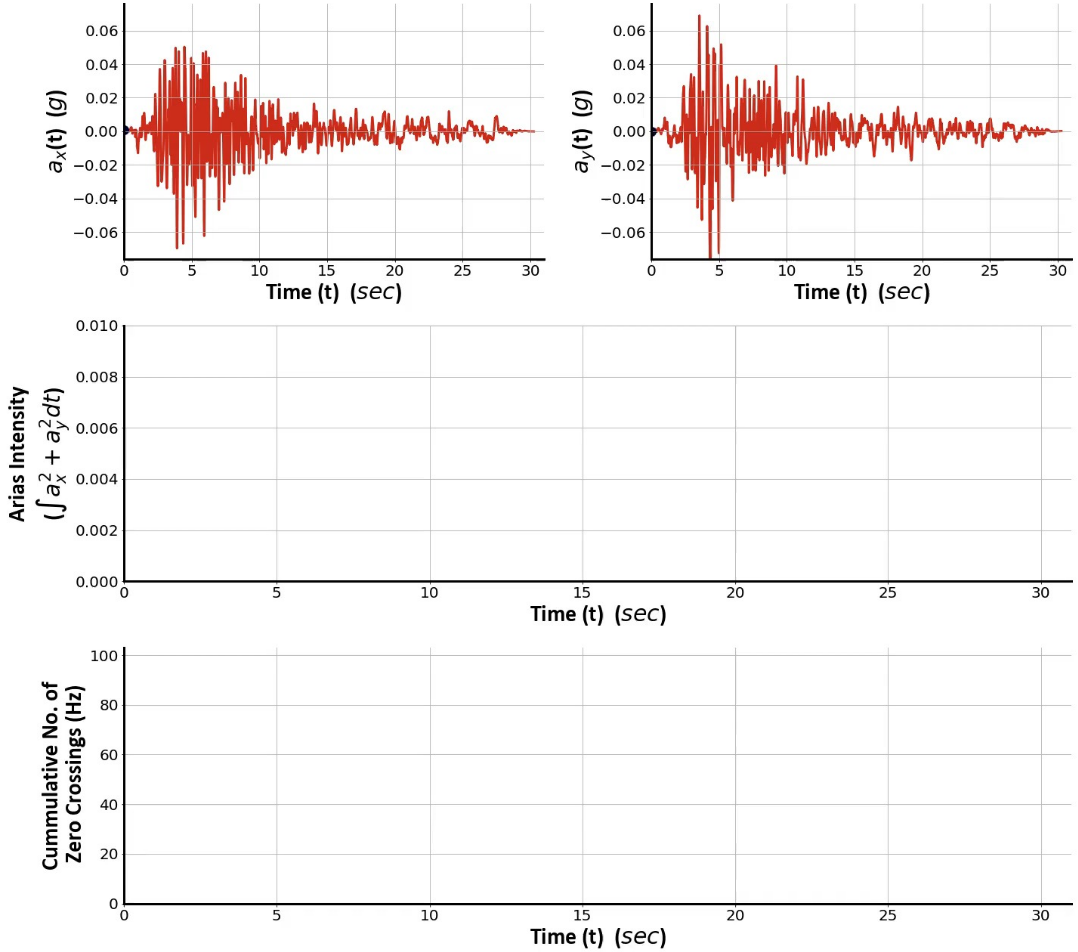
Ground Motion Parameters

Rezaeian, S., Zhong, P., Hartzell, S., Zareian, F. Validation of Simulated Earthquake Ground Motions Based on Evolution of Intensity and Frequency Content. *Bulletin of the Seismological Society of America*,

RZZ Parameters: $\mathbf{RZZ}(I_a, f_{mid}, D_{5-95}, etc.)$



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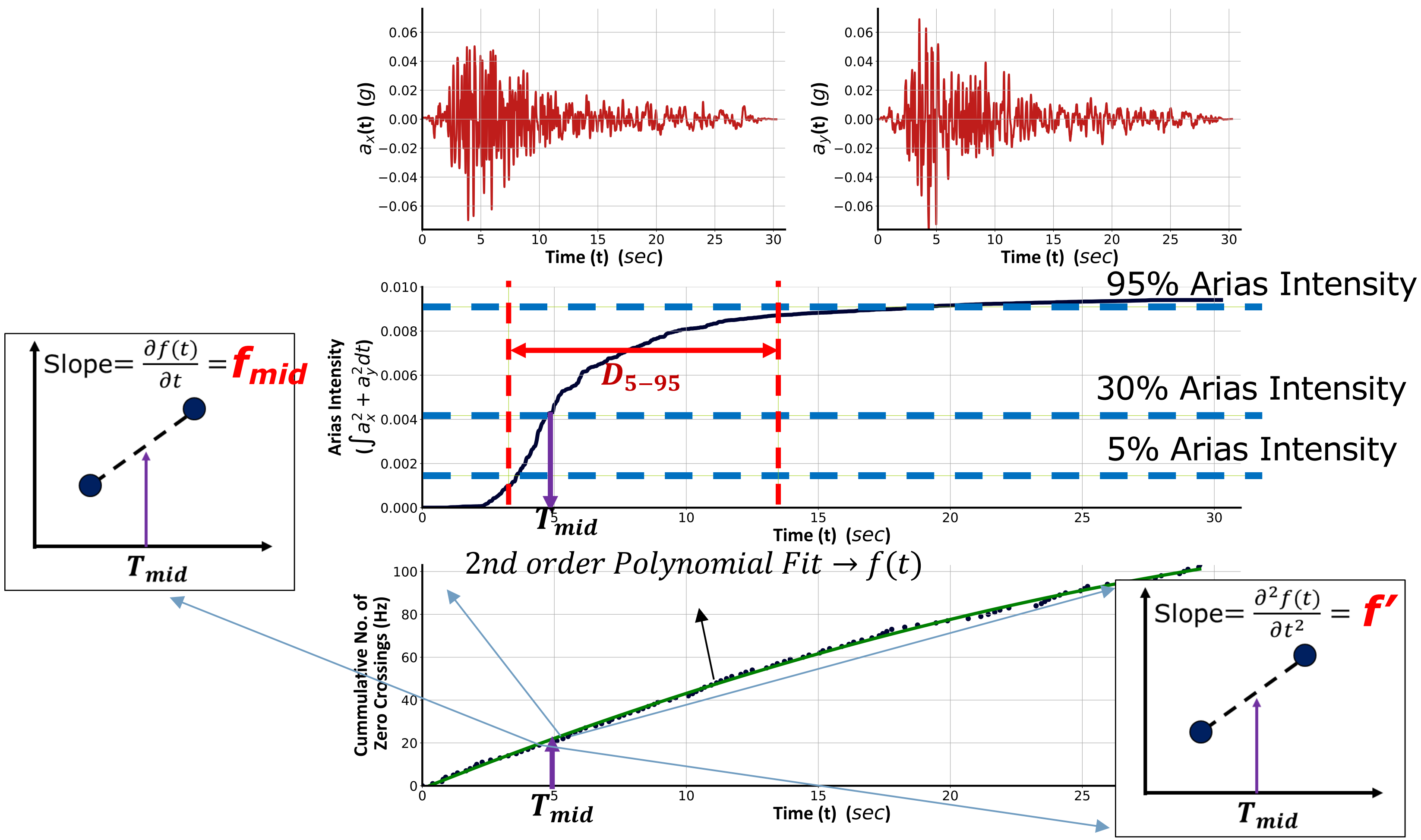

Type III, Ground Motion Simulation Validation

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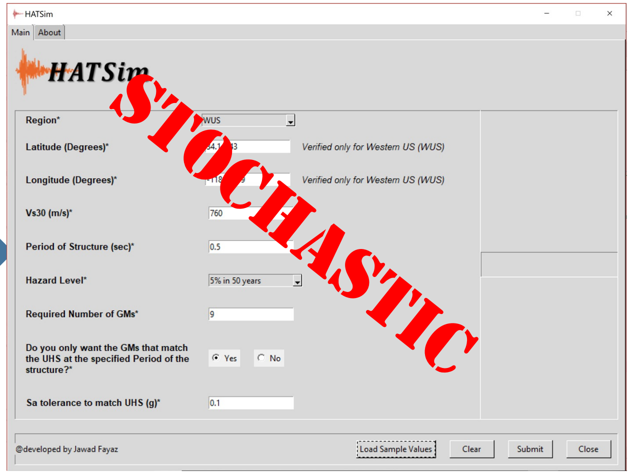

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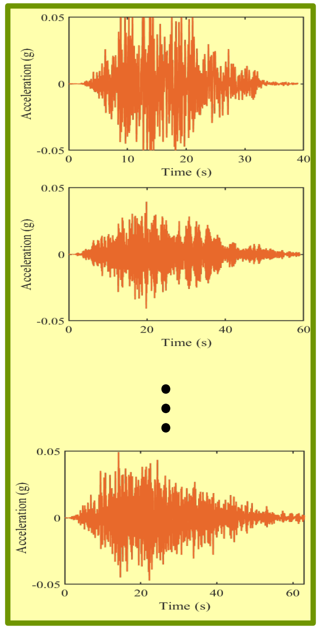

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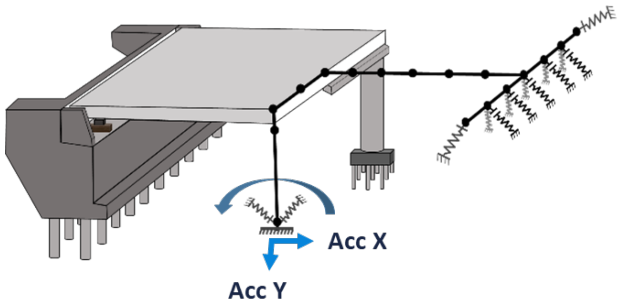

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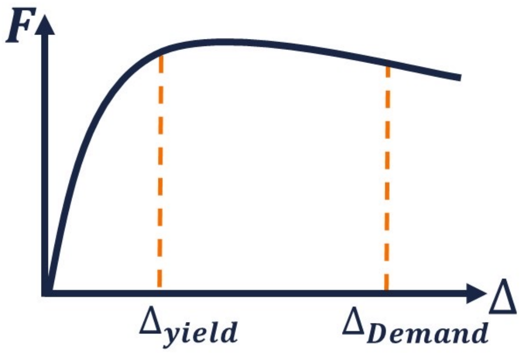

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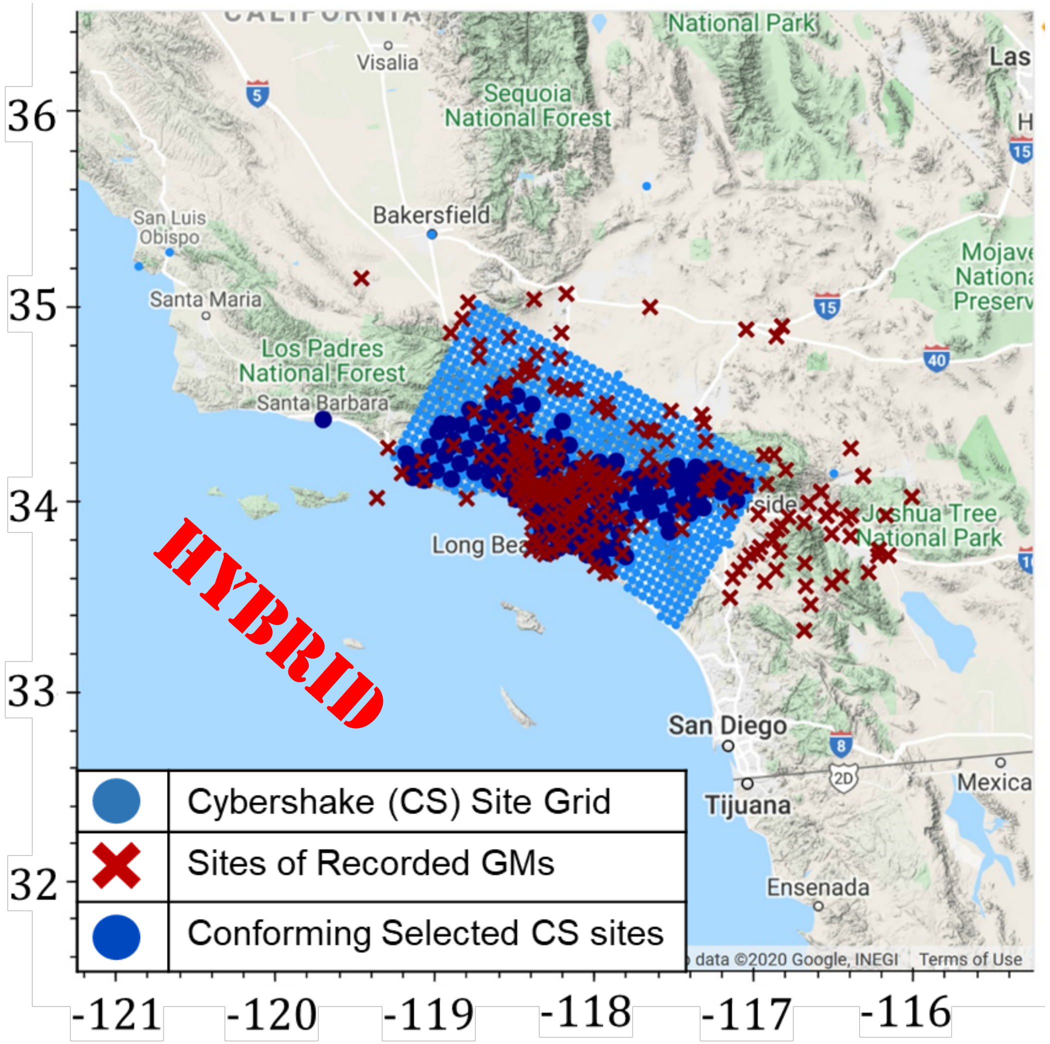
Type II, Ground Motion Simulation Validation (Regional)

1 catalog of natural ground motions from the past 100 years (288 ground motions)

100 catalogs of simulated ground motions for 100 years (~300 ground motions/catalog)

Similar statistics of event parameters (θ)



Fayaz J., Azar S., Dabaghi M., and Zareian F. (2020). "Methodology for Validation of Simulated Ground Motions for Seismic Response Assessment: Application to Cybershake Source-based Ground Motions." *BSSA*.

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Type II, Ground Motion Simulation Validation (Regional)

Approach

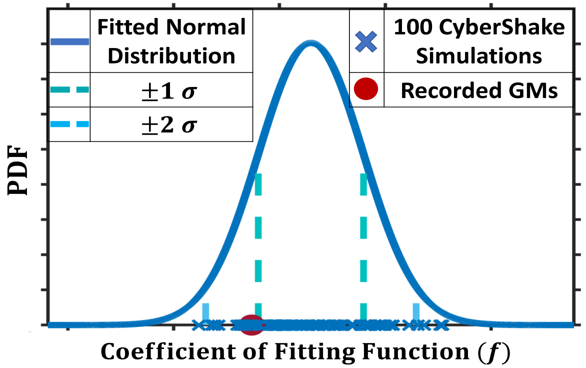
Event Parameters: $\boldsymbol{\theta}(M, R, V_{s30}, etc.)$ → RZZ Parameters: $\mathbf{RZZ}(I_a, f_{mid}, D_{5-95}, etc.)$ → EDP: $Rot50CDR$

$$\ln(\widehat{EDP}) = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + f_{hyp} + f_{dip}$$

$$\ln(\widehat{RZZ}) = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + f_{hyp} + f_{dip}$$

$$\ln(\widehat{EDP}) = f_{I_{a,maj}} + f_{I_{a,min}} + f_{f_{mid,maj}} + f_{f_{mid,min}} + f_{f'_{maj}} + f_{f'_{min}} + f_{T_{mid,maj}} + f_{T_{mid,min}}$$

Does the coefficient of each f for the recorded catalogue fall within ±2σ of the same coefficient of the simulated catalogues



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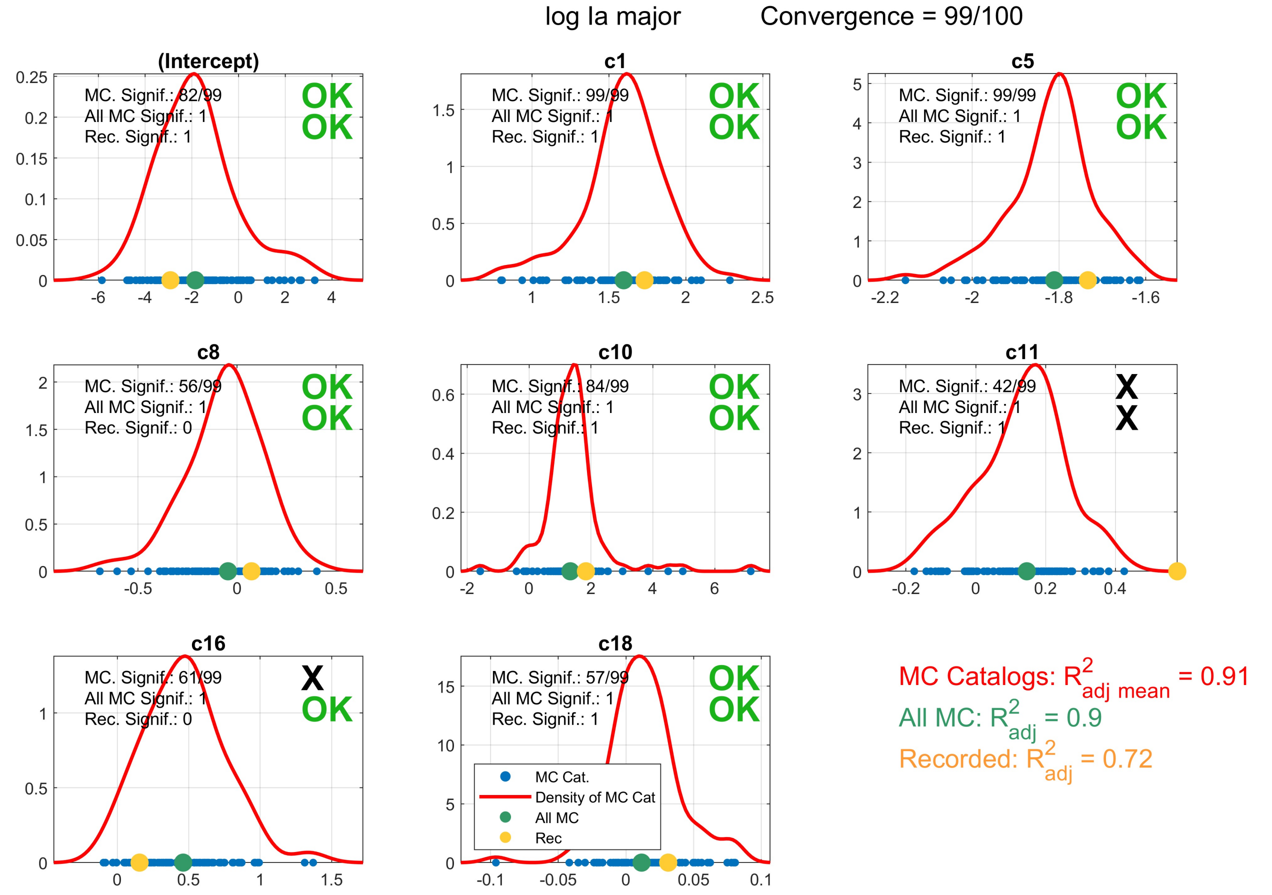
Type II, Ground Motion Simulation Validation (Regional)

Sample



Each Sim.

Dist. Sim.

Med. Sim

The Rec.

Fayaz J., Azar S., Dabaghi M., and Zareian F. (2020). "Methodology for Validation of Simulated Ground Motions for Seismic Response Assessment: Application to Cybershake Source-based Ground Motions." *BSSA*.

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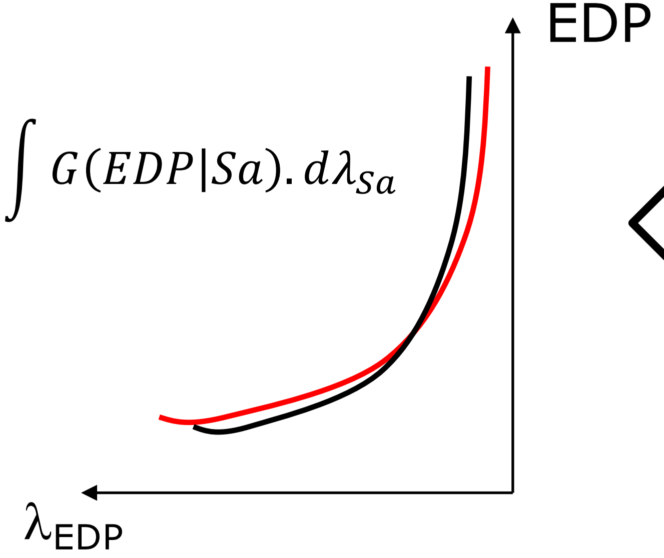
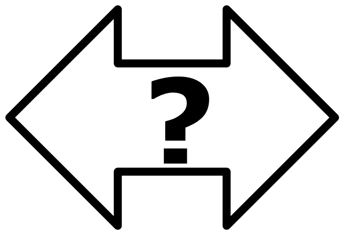
Type II, Ground Motion Simulation Validation (Hazard)

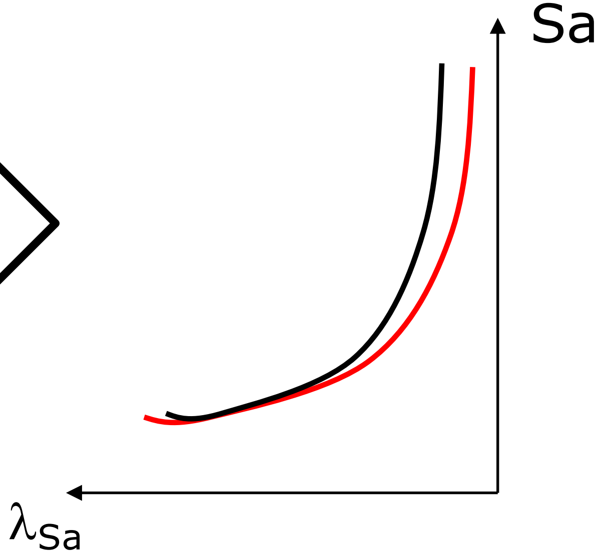
- Mean Annual Frequency (MAF) of Spectral Acceleration and EDPs.

$(\lambda_{EDP_{sim}}$ vs. $\lambda_{EDP_{rec}}$ VS. $\lambda_{Sa_{sim}}$ vs. $\lambda_{Sa_{rec}})$

$$\lambda_{EDP} = \int G(EDP|Sa).\, d\lambda_{Sa}$$



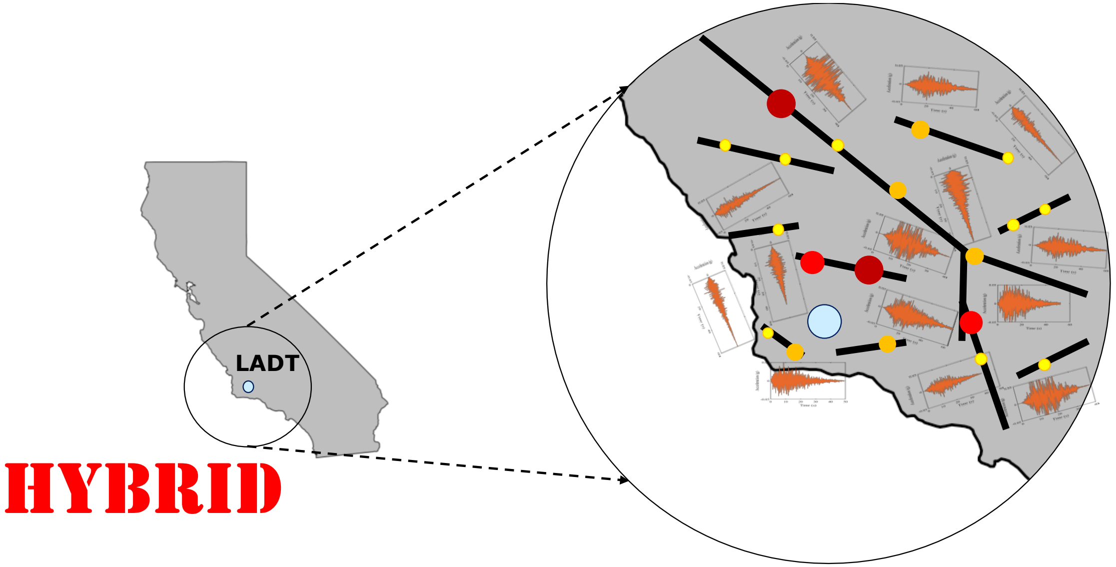


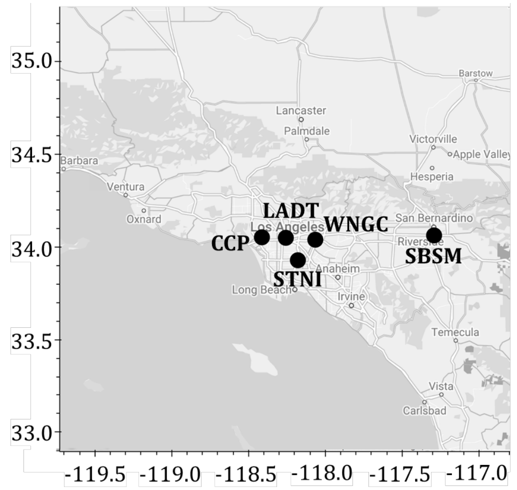


1. Do $\lambda_{Sa_{rec}}$ & $\lambda_{Sa_{sim}}$ match?
2. Do statistics of $EDP_{rec}|Sa_{rec}$ match $EDP_{sim}|Sa_{sim}$?
3. Can differences in $\lambda_{EDP_{sim}}$ & $\lambda_{EDP_{rec}}$ be explained by differences in #1 and #2.

Fayaz J., Rezaeian S., and Zareian F., (2021). "Evaluation of Simulated Ground Motions using Probabilistic Seismic Demand Analysis: CyberShake (ver. 15.12) Simulations for Ordinary Standard Bridges." *Earthquake Engineering and Soil Dynamics*.

Type II, Ground Motion Simulation Validation (Hazard)





Site	$V_{s30}\ (m/s)$ (CVM 4.26)	$Z_{2.5}\ (km)$ (CVM 4.26)	No. of GMs in 200,000-year catalogs	No. of Pulse-Like GMs in catalogs
LADT	358.65	2.08	20,984	783
SBSM	354.84	1.77	22,848	1721
CCP	361.69	2.96	19,822	965
WNGC	295.94	2.44	21,359	1167
STNI	268.52	5.57	20,415	1014

Fayaz J., Rezaeian S., and Zareian F., (2021). "Evaluation of Simulated Ground Motions using Probabilistic Seismic Demand Analysis: CyberShake (ver. 15.12) Simulations for Ordinary Standard Bridges." *Earthquake Engineering and Soil Dynamics*.

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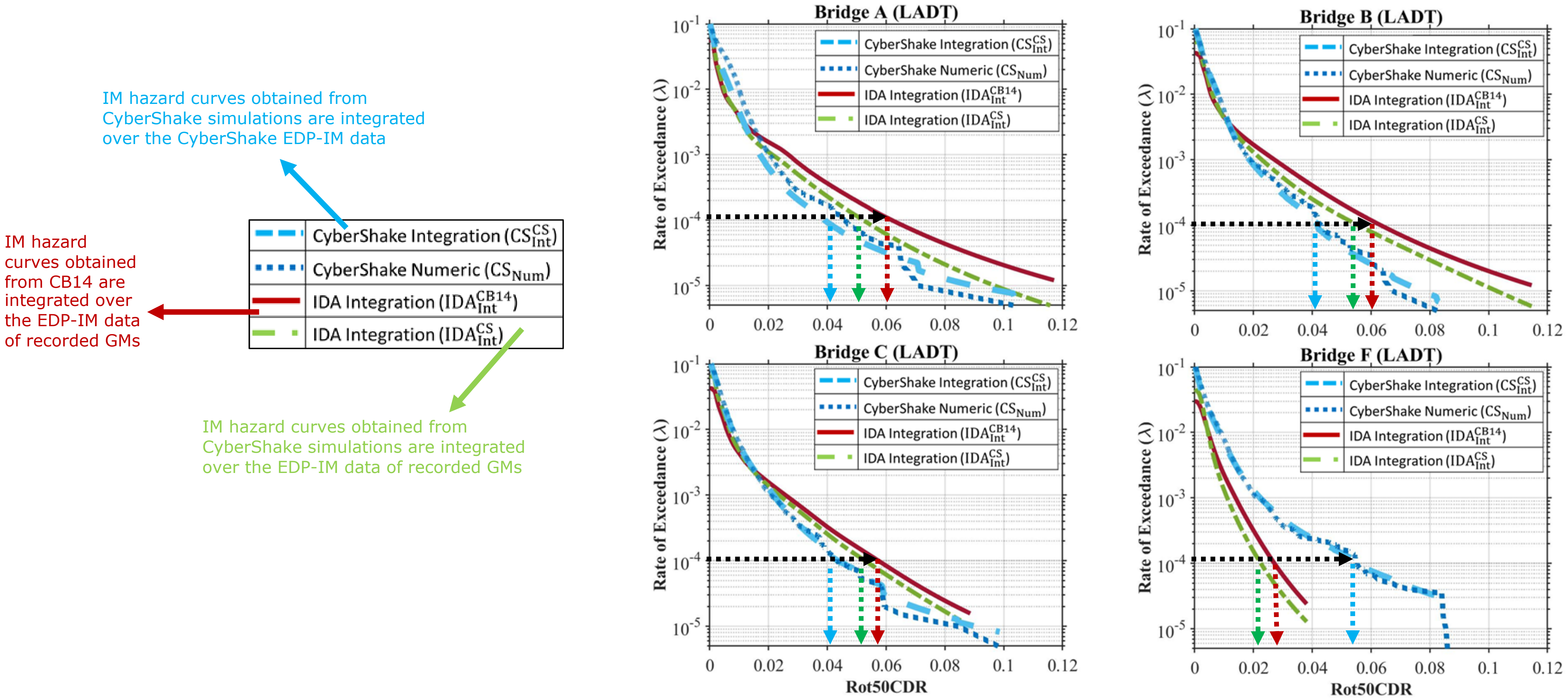

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Summary

- ✓ Simulated GMs are here to stay.
- ✓ Types of validation.
- ✓ GM simulation validation is highly application dependent.
- ✓ Parameters and Metrics for waveform validation are proposed and utilized for improvement of simulation models.

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PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Stochastic Modeling and Simulation of Ground Motions for Performance-Based Earthquake Engineering

Sanaz Rezaeian
and
Armen Der Kiureghian
University of California, Berkeley

PEER 2010/02
JUNE 2010

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Stochastic Modeling and Simulation of Near-Fault Ground Motions for Performance-Based Earthquake Engineering

Mayssa Dabaghi
Armen Der Kiureghian
Department of Civil and Environmental Engineering
University of California, Berkeley

PEER Report 2014/20
Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley

December 2014

PEER 2014/20
DECEMBER 2014

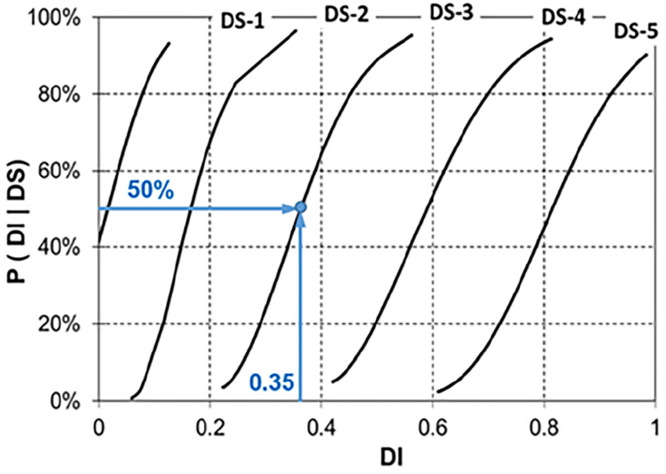
New Frontiers

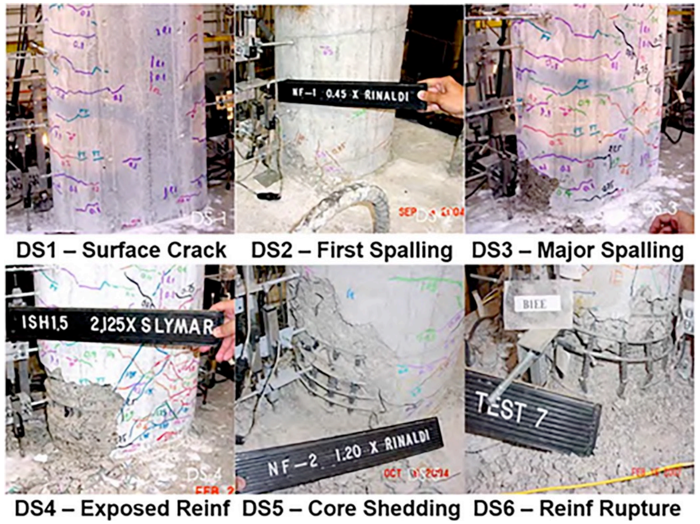
Probabilistic Damage Control Application: Implementation of Performance-Based Earthquake Engineering in Seismic Design of Highway Bridge Columns

Yeo Hoon Yoon, P.E.[1]; Sam Ataya, P.E.[2]; Mark Mahan, Ph.D., P.E., M.ASCE[3]; Amir Malek, Ph.D., P.E.[4]; M. Saiid Saiidi, Ph.D., P.E., F.ASCE[5]; and Toorak Zokaie, Ph.D., P.E., M.ASCE[6]

$$IM \Rightarrow DI_D$$

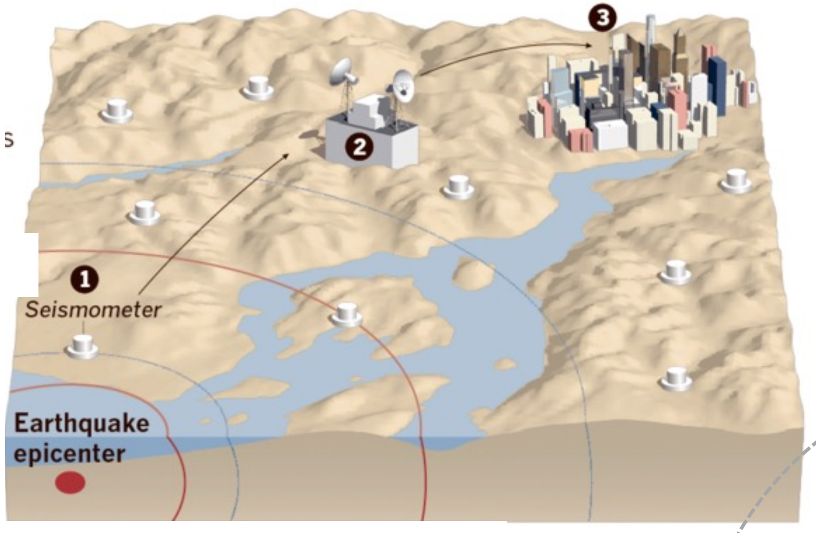
$$DI_C \Leftarrow DM_i$$



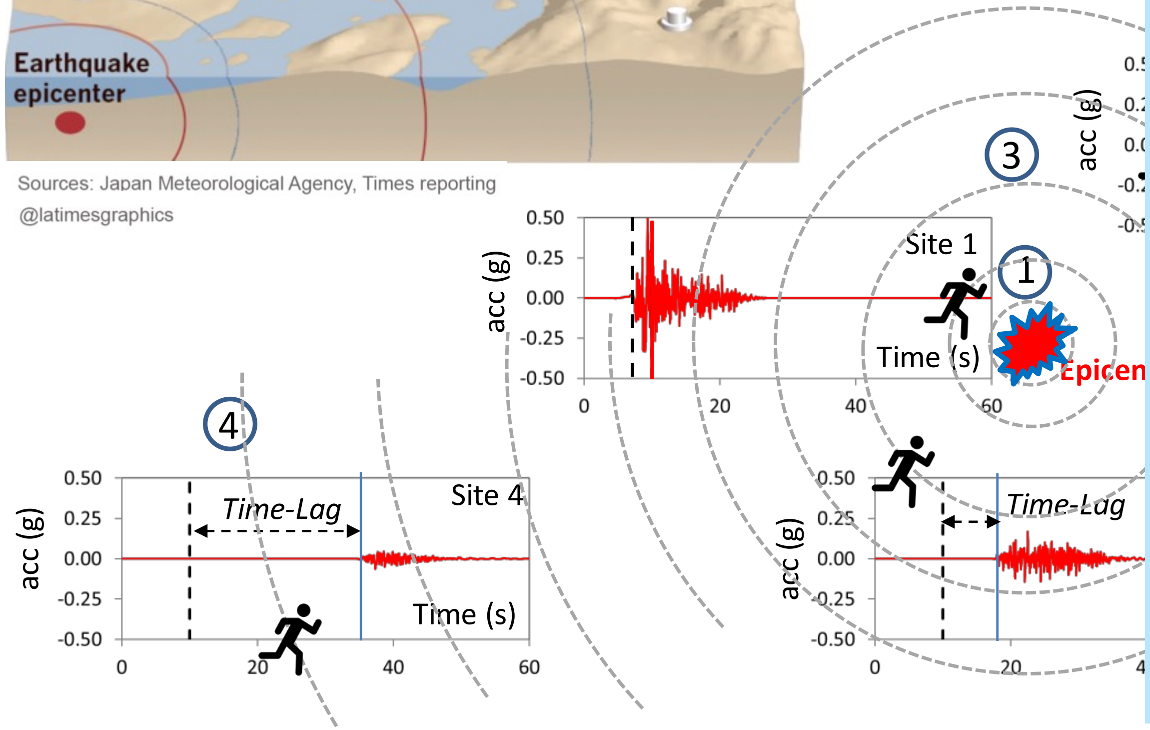


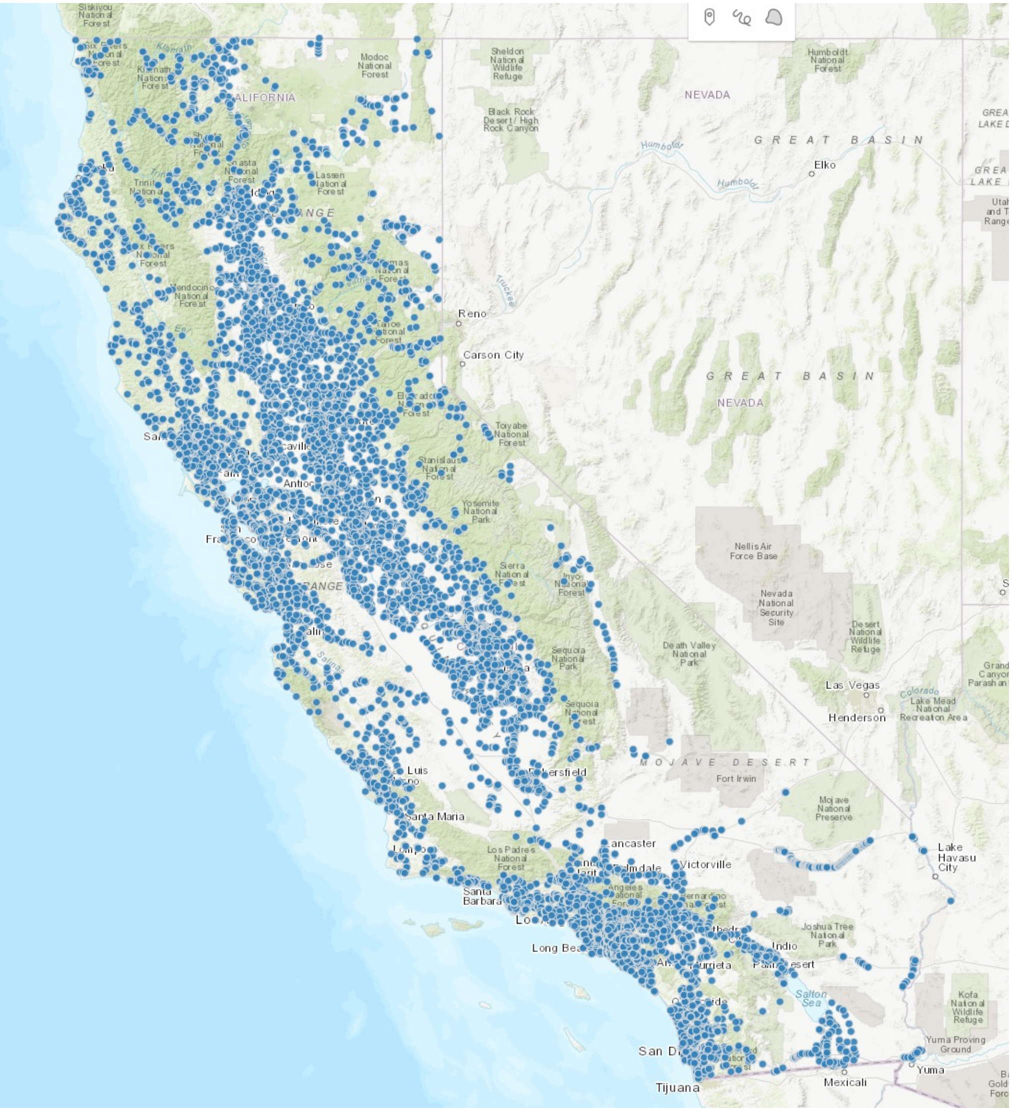
$$\beta_i = \frac{ln\left(\frac{\mu_{Ri}}{\mu_L}\sqrt{\frac{\delta_L^2+1}{\delta_{Ri}^2+1}}\right)}{\sqrt{ln\left[(\delta_L^2+1)(\delta_{Ri}^2+1)\right]}}$$

New Frontiers



Sources: Japan Meteorological Agency, Times reporting
@latimesgraphics





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&
Questions

"Amateurs Practice Until They Get It Right;
Professionals Practice Until They Can't Get It Wrong"

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