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Validation and Utilization of Physics-Based Simulated Ground Motions for Bridge Performance Assessment

2020 PEER Annual Meeting

The Future of Performance-Based Natural Hazards Engineering

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PEER

American University of Beirut

SCEC

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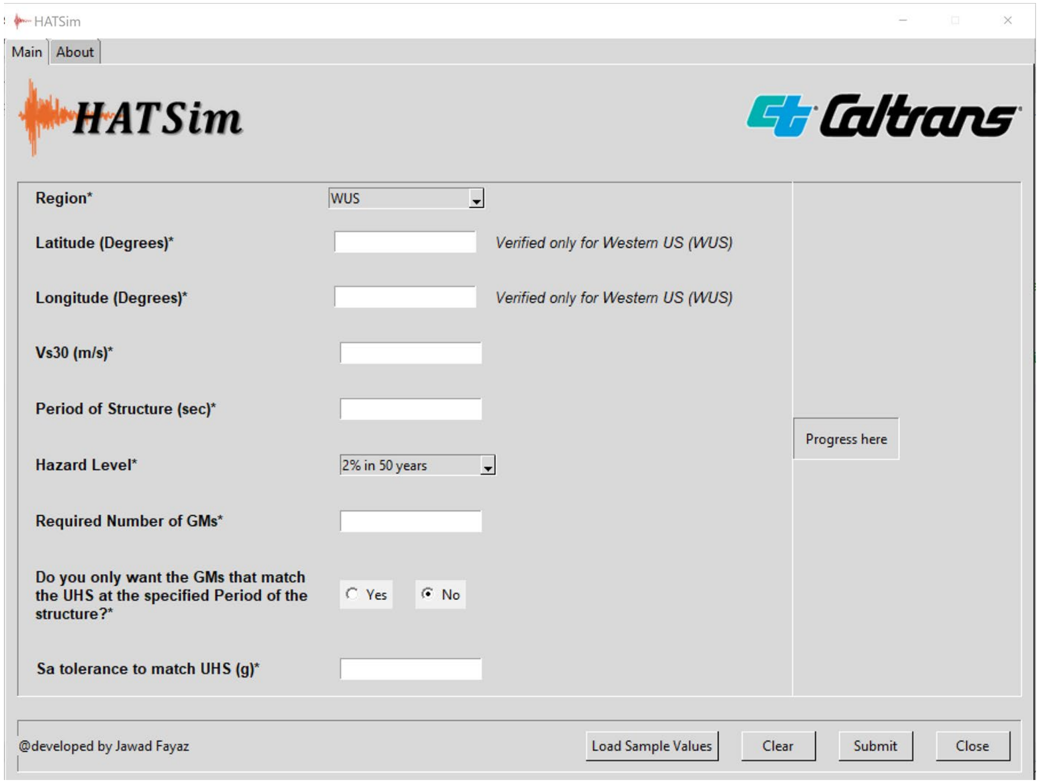
Acknowledgement

- Performance-based seismic assessment of skewed bridges (PEER TSRP 2008, with UCLA)
- Guidelines for Nonlinear Seismic Analysis of Ordinary Bridges: Version 2.0 (Caltrans 2011, with UCB and UCLA)
- Quantification of Variability in Performance Measures of Ordinary Bridges to Uncertainty in Seismic Loading Directionality and Its Implication in Engineering Practice. (PEER Lifelines 2012, with CSU-Chico)
- Guidelines for Ground Motion modeling for Performance Based Earthquake Engineering of Ordinary Bridges (Caltrans 2017)



https://faculty.sites.uci.edu/pbee/links/

Acknowledgement


Mayssa Dabaghi


Jawad Fayaz


Sarah Azar


Farzin Zareian

Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG)

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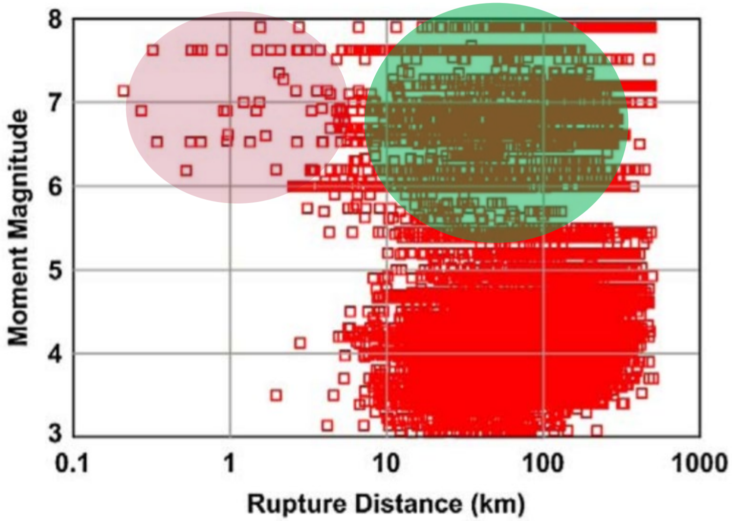
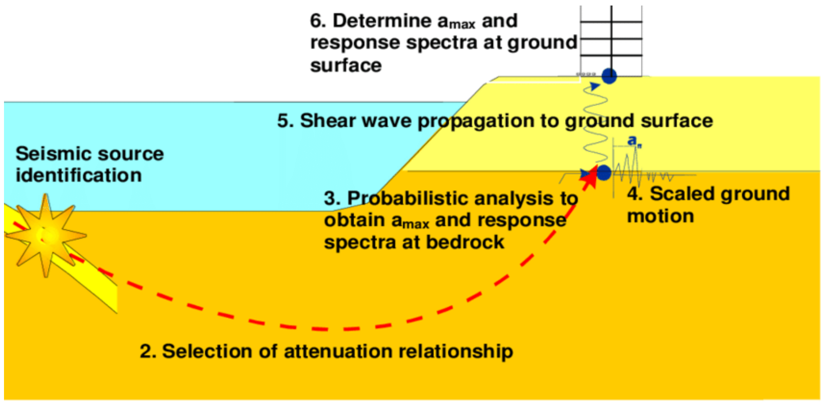
Need for simulated ground motions

IM → *EDP* → *DM* → *DV*



Kenneth W. Campbell and Yousef Bozorgnia (*2014*) NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV, and 5% Damped Linear Acceleration Response Spectra. Earthquake Spectra: August 2014, Vol. 30, No. 3, pp. 1087-1115.



Ground motions can be simulated for specific fault geometries and include the region-specific characteristics of the wave propagation problem.

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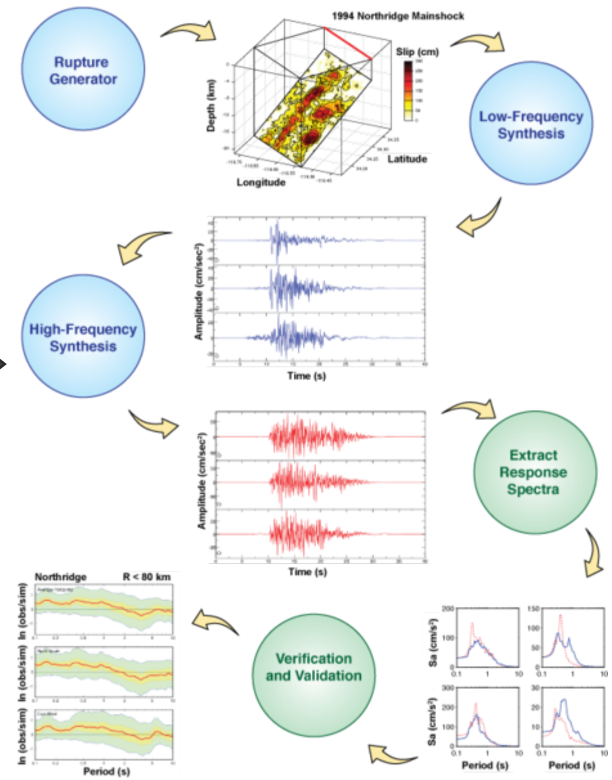
Generating simulated ground motions

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



SIMQKE

(Gasparini and **Vanmarke** , 1976)

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

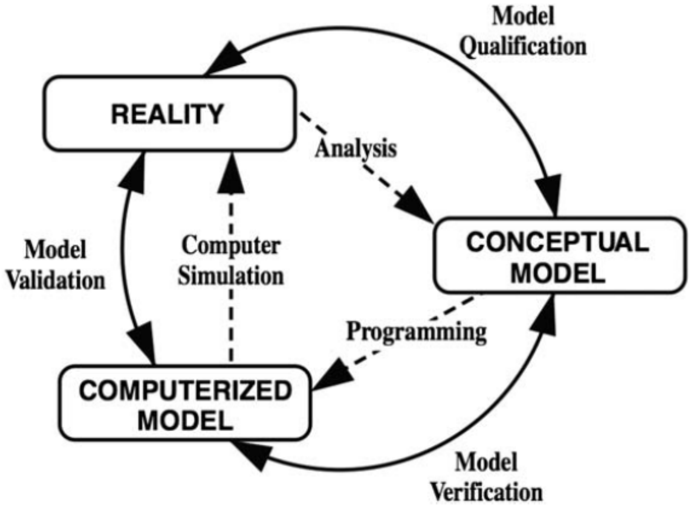
Sanaz Rezaeian
and
Armen Der Kiureghian
University of California, Berkeley

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

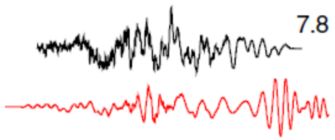
Validating simulated ground motions

- Key Issues in validation of simulated motions
  - Independent of simulation method
  - Dependent on engineering application
- Key steps in validation of simulated motions
  - Identify validation parameters.
  - Obtain best estimate of the validation parameters.
  - Compare validation parameters for simulated motions against their best estimate.
  - Judgement.



Oberkampf, W. L., Trucano, T. G., and Hirsch, C., 2002. Verification, validation, and predictive capability in computational engineering and physics

Validating simulated ground motions



a)Comparison between waveform shapes. (comparing wiggles)

b)Spectral Acceleration and EDPs of recorded data from past earthquakes. (Sa_{rec} to Sa_{sim}, EDP_{rec} to EDP_{sim})

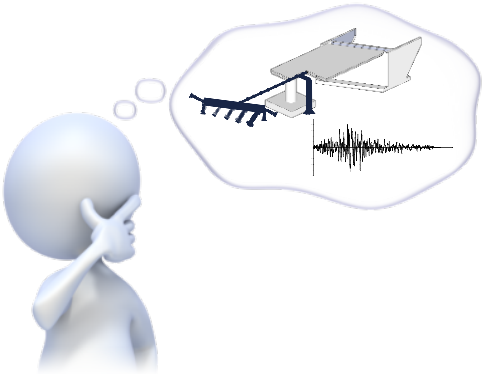
c) Enhanced Intensity Measures of recorded data from past earthquakes. (RZZ_{rec} to RZZ_{sim})

d)Intensity Measure of simulated motions to empirical ground motion models. (IM_{sim} to IM_{GMPE})

e)Enhanced Intensity Measures of simulated motions to empirical ground motion models. (RZZ_{sim} to RZZ_{GMPE})

f)EDP conditioned on similarity of response spectra. (conditioned on similarity of Sa_{rec} to Sa_{sim})

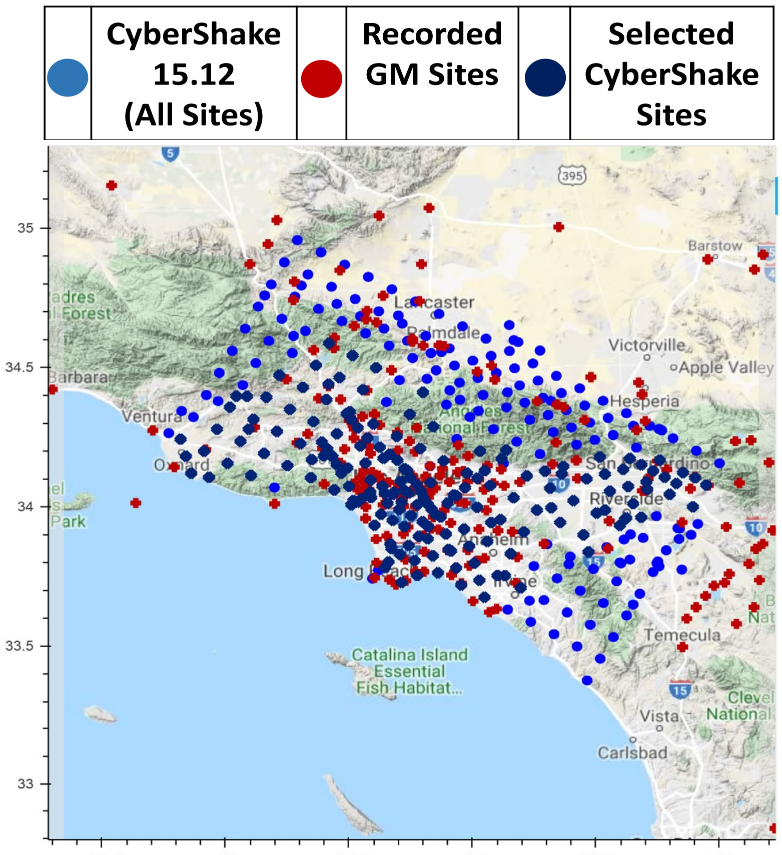
Problem Statement



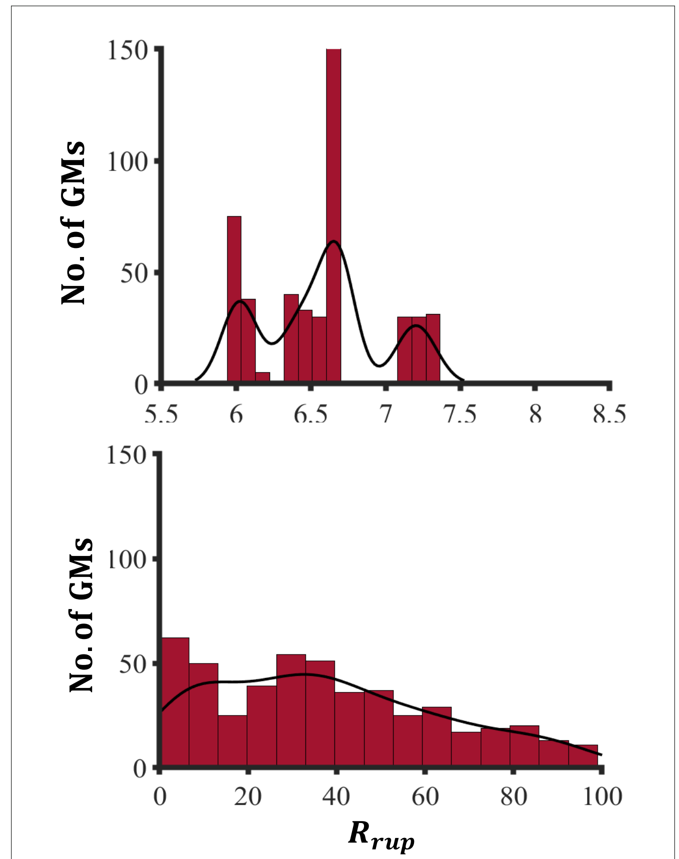
- Can we develop a validation test for simulated ground motions intended for the performance assessment of ordinary bridges?

- Can we use physics-based simulated ground motions for the performance assessment of ordinary bridges?

Approach



Identified distribution of event parameters (θ) in the past years from NGAWest2



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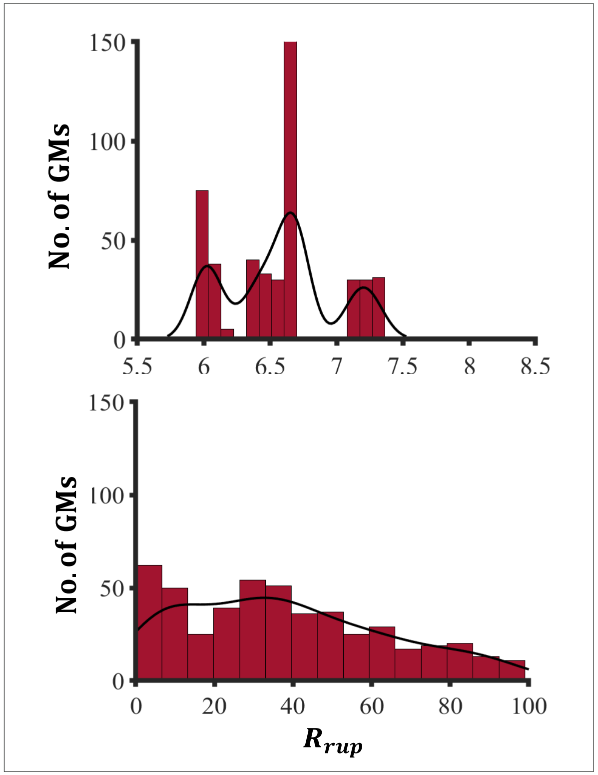
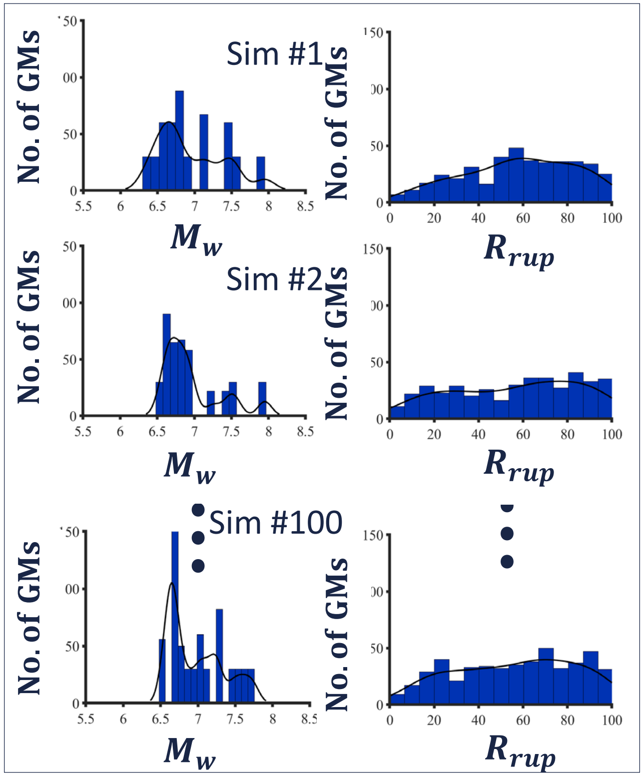
Approach



One catalogue of recorded ground motions.

Similar statistics of event parameters (θ)

100 catalogues of simulated ground motions.



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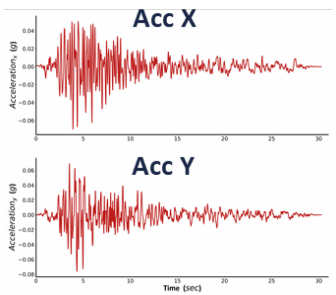
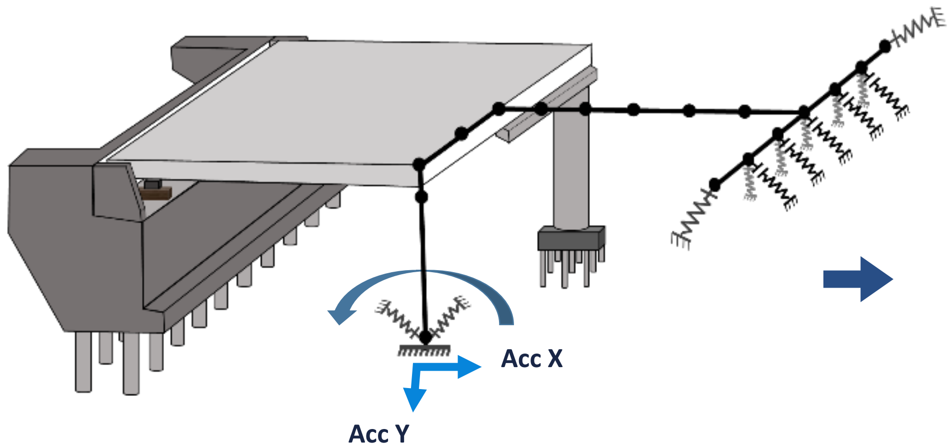
Approach





Rot50CDR
Column Drift Ratio

Rotation Angle	Column Drift Ratio
0°	$0.2\ \%$
9°	$0.21\ \%$
171°	$0.27\ \%$
180°	$0.2\ \%$

$$Rot50CDR = median\begin{Bmatrix} 0.2\ \% \\ 0.21\ \% \\ \vdots \\ 0.27\ \% \\ 0.2\ \% \end{Bmatrix}$$

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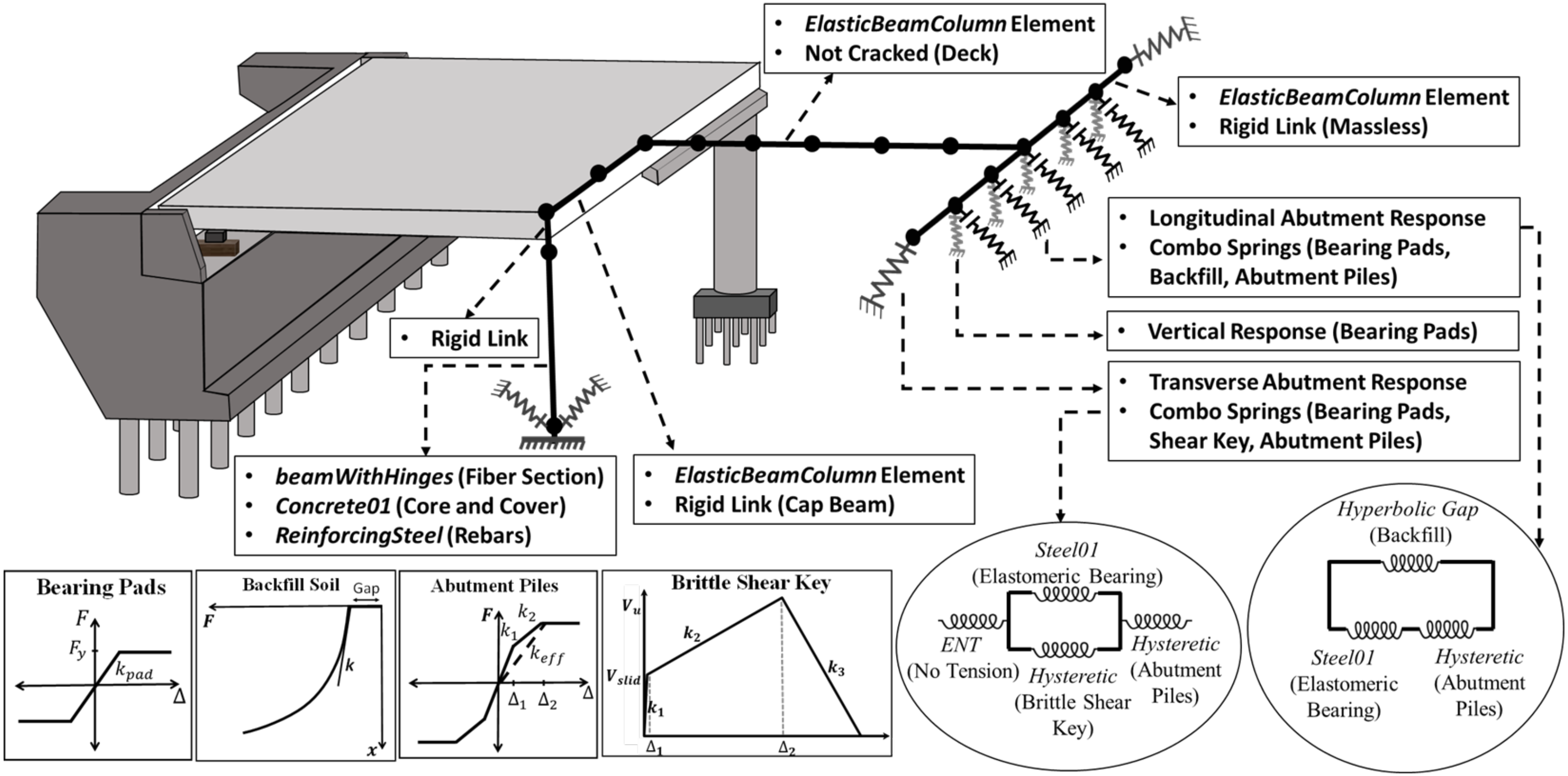
Approach



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

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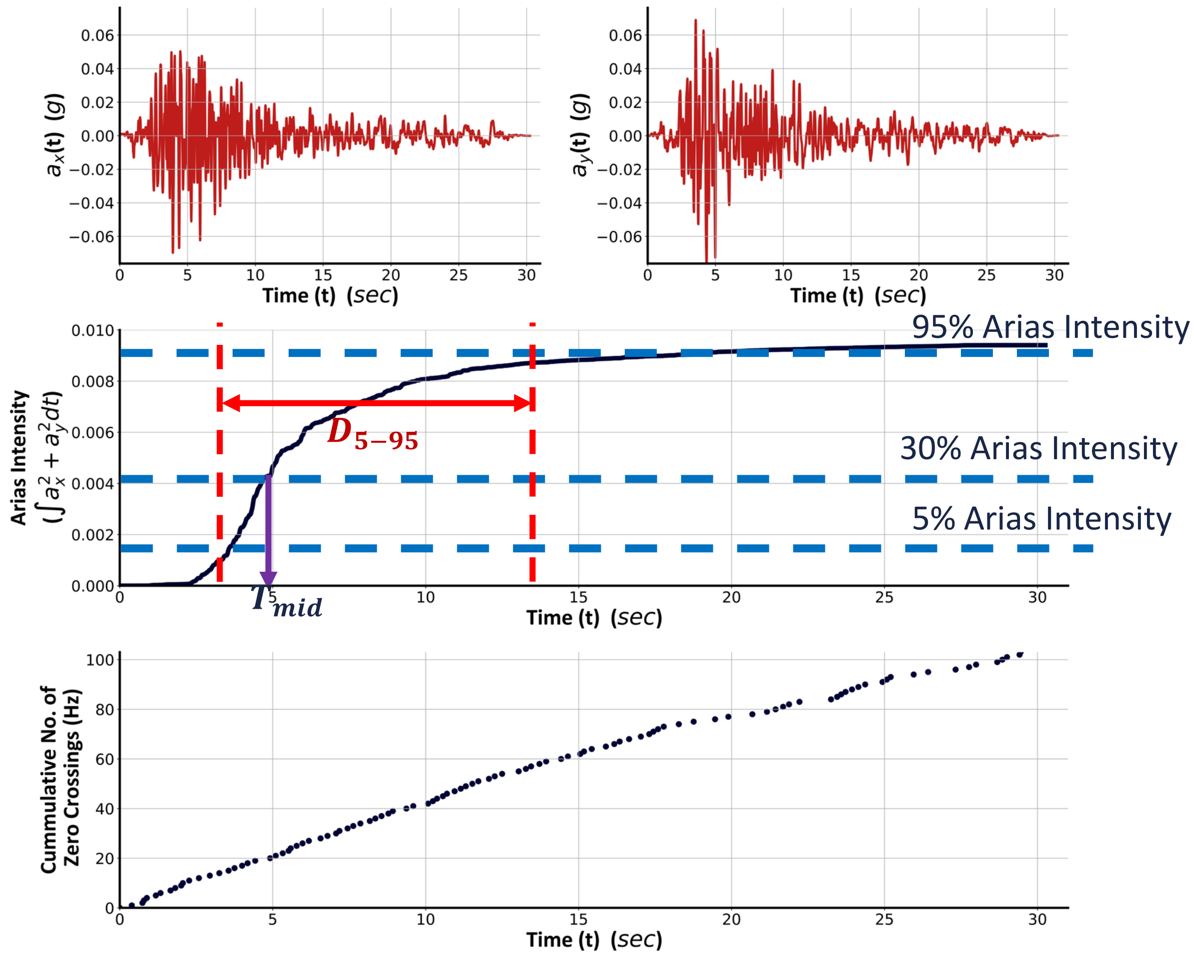

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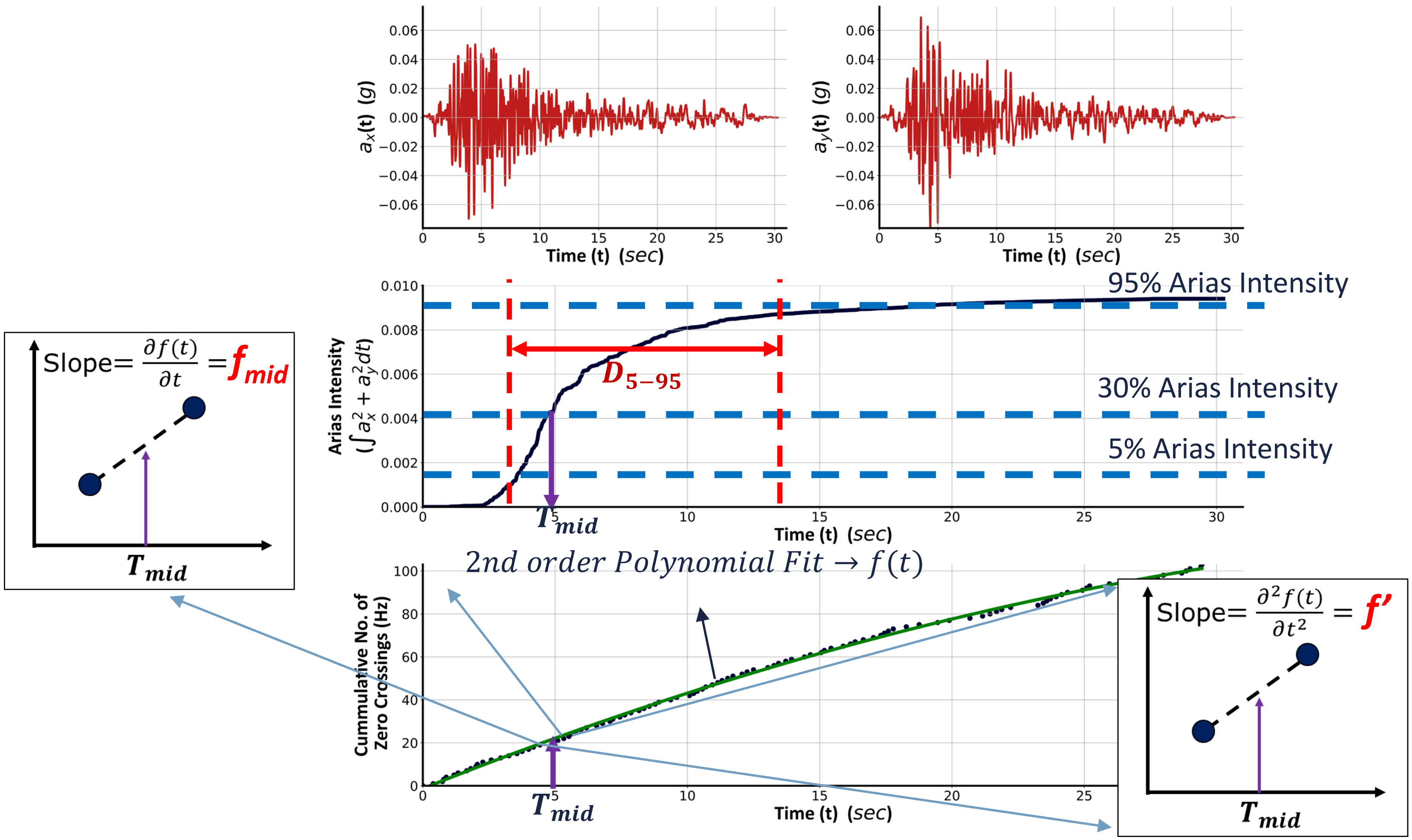


Approach

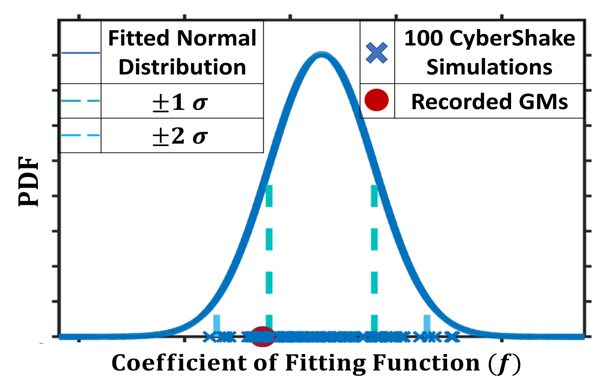
Event Parameters: $\boldsymbol{\theta}(M, R, V_{s30}, etc.)$ → RZZ Parameters: $\mathbf{RZZ}(I_a, f_{mid}, D_{5-95}, etc.)$ → EDP: $Rot50CDR$

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

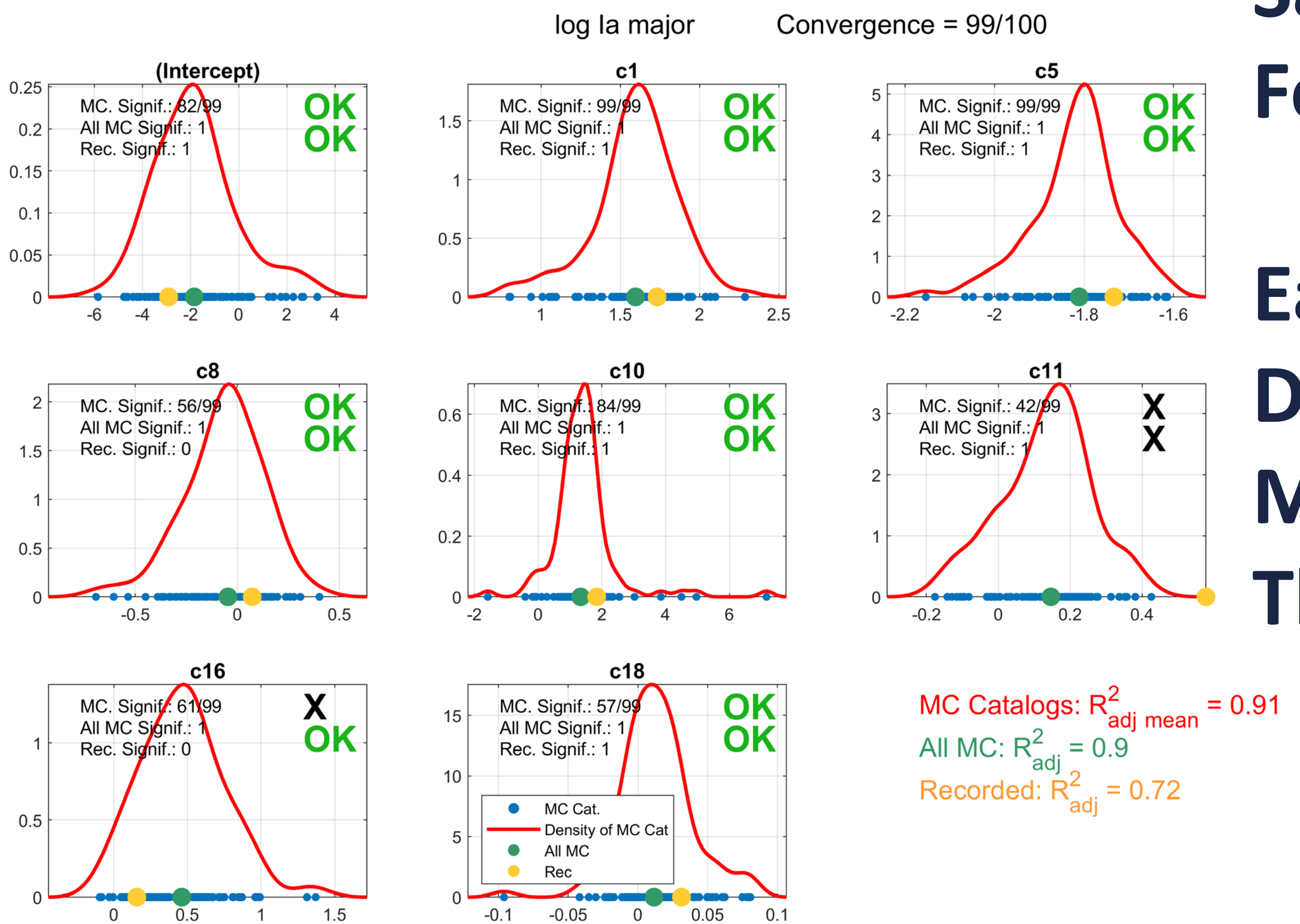
$$\ln(\widehat{RZZ}) = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + f_{hyp} + f_{dip}$$

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

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



Approach



Sample

For internal use

Each Sim.

Dist. Sim.

Med. Sim

The Rec.

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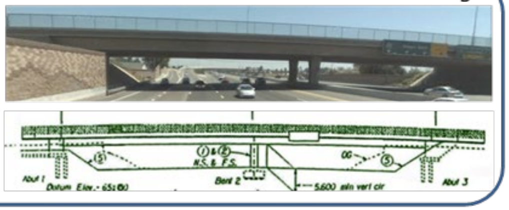
Bridge B: Two-Span Multi-Column

- Spans: 155 ft + 145 ft
- Located in the City of Tustin
- Built in 2000

The La Veta Avenue Overcrossing

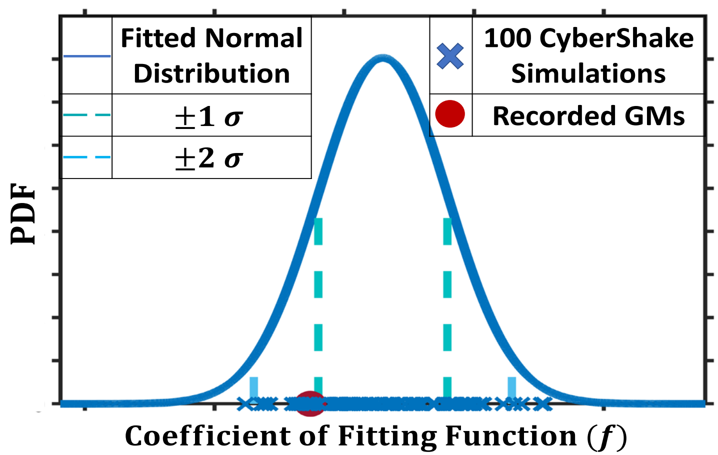


Results

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

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

EDP	$Bias$	f_{mag}	f_{dis}	f_{site}	f_{sed}	f_{hyp}
$\pm 1\ \sigma$	✓	✓	✗	✓	✓	✓
$\pm 2\ \sigma$	✓	✓	✓	✓	✓	✓



Relations between the Event parameters and EDP for recorded and simulated GMs tend to be statistically similar

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Results

Bridge B: Two-Span Multi-Column

- Spans: 155 ft + 145 ft
- Located in the City of Tustin
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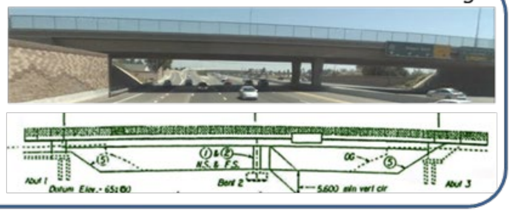
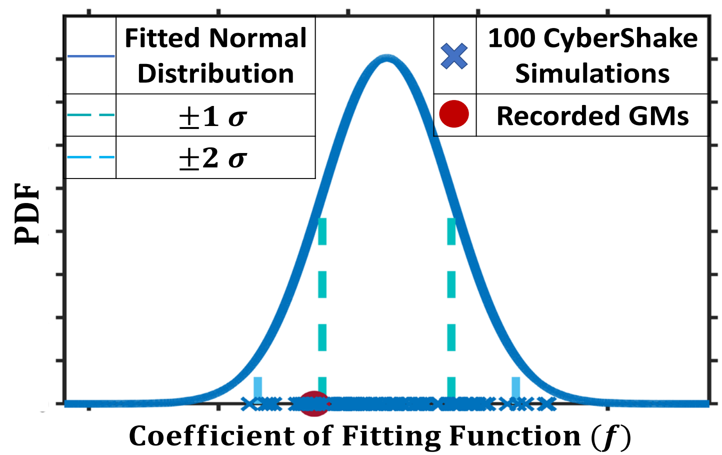


Event Parameters: $\boldsymbol{\theta}(M, R, V_{s30}, etc.)$ RZZ Parameters: $\mathbf{RZZ}(I_a, f_{mid}, D_{5-95}, etc.)$ → EDP: $Rot50CDR$

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

EDP	*Bias*	$f_{I_{a,maj}}$	$f_{I_{a,min}}$	$f_{f_{mid,maj}}$	$f_{f_{mid,min}}$	$f_{f'_{maj}}$	$f_{f'_{min}}$	$f_{D_{5-95,maj}}$	$f_{D_{5-95,min}}$
$\pm 1\ \sigma$	✗	✓	✓	✓	✗	✓	✗	✓	✓
$\pm 2\ \sigma$	✓	✓	✓	✓	✓	✓	✓	✓	✓



Relations between the RZZ parameters and EDP for recorded and simulated GMs tend to be statistically similar (and sufficient)

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Results

Bridge B: Two-Span Multi-Column

- Spans: 155 ft + 145 ft
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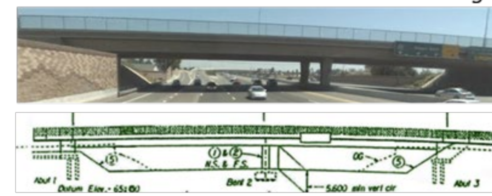
The La Veta Avenue Overcrossing



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

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

$I_{a,maj}$	$Bias$	f_{mag}	f_{dis}	f_{hng}	f_{site}	f_{sed}	f_{hyp}
$\pm 1\,\sigma$	✓	✓	✓	✓	✗	✗	✓
$\pm 2\,\sigma$	✓	✓	✓	✓	✗	✓	✓

$f_{mid,maj}$	$Bias$	f_{mag}	f_{dis}	f_{hng}	f_{site}	f_{sed}	f_{hyp}
$\pm 1\,\sigma$	✓	✓	✓	✓	✓	✗	✗
$\pm 2\,\sigma$	✓	✓	✓	✓	✓	✓	✓

$D_{5-95,maj}$	$Bias$	f_{mag}	f_{dis}	f_{hng}	f_{site}	f_{sed}	f_{hyp}
$\pm 1\,\sigma$	✗	✗	✗	✓	✗	✗	✓
$\pm 2\,\sigma$	✓	✓	✓	✓	✓	✗	✓

$f'_{mid,maj}$	$Bias$	f_{mag}	f_{dis}	f_{hng}	f_{site}	f_{sed}	f_{hyp}
$\pm 1\,\sigma$	✗	✗	✗	✓	✓	✓	✗
$\pm 2\,\sigma$	✓	✓	✗	✓	✓	✓	✓

Validation of simulated motions based on RZZ parameters is ~stringent

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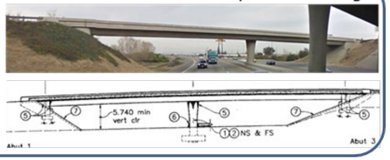
Next Steps

- Repeat for 3 other bridge structures.
- Conduct a similar study but using Broadband simulations (event parameters of the simulation catalogues will be identical to the recorded one).

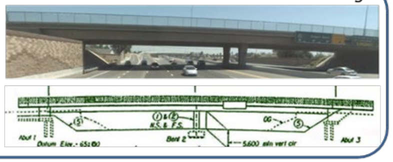
The Jack Tone Road On-Ramp Overcrossing

Bridge A: Two-Span Single-Column
- Spans: 108 ft + 112 ft
- Located in the City of Ripon
- Built in 2001



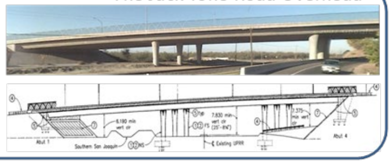
The La Veta Avenue Overcrossing

Bridge B: Two-Span Multi-Column
- Spans: 155 ft + 145 ft
- Located in the City of Tustin
- Built in 2000



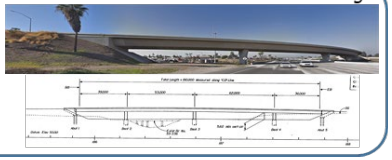
The Jack Tone Road Overhead

Bridge C: Three-Span Multi-Column
- Spans: 156 ft + 144 ft + 118 ft
- Located in the City of Ripon
- Built in 2001



E22-N55 Connector Over-crossing

Bridge F: Four-Span Single-Column
- Spans: 39 ft + 53 ft + 62 ft + 36 ft
- Located in Santa Ana
- Built in 2001



Current Differences	CyberShake	Broadband Platform
Purpose	PSHA	Scenarios
Methods	Graves & Pitarka	Several (7)
Basin effects	3-dimensional	1-dimensional
Frequency band	~~< ~1 Hz~~	0-100 Hz
Computer needed	Supercomputer	Personal computer
Validations	Relatively limited	Relatively extensive

- Develop a validation test for simulated ground motions intended for the performance assessment of ordinary bridges.

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http://www.businesscoachmichaeldill.com/do-you-have-what-it-takes-to-reach-the-summit/

Thank You