Development of a Performance-Based Multi-hazard Engineering (PBME) Framework Consistent with Existing Single-hazard PBE Frameworks

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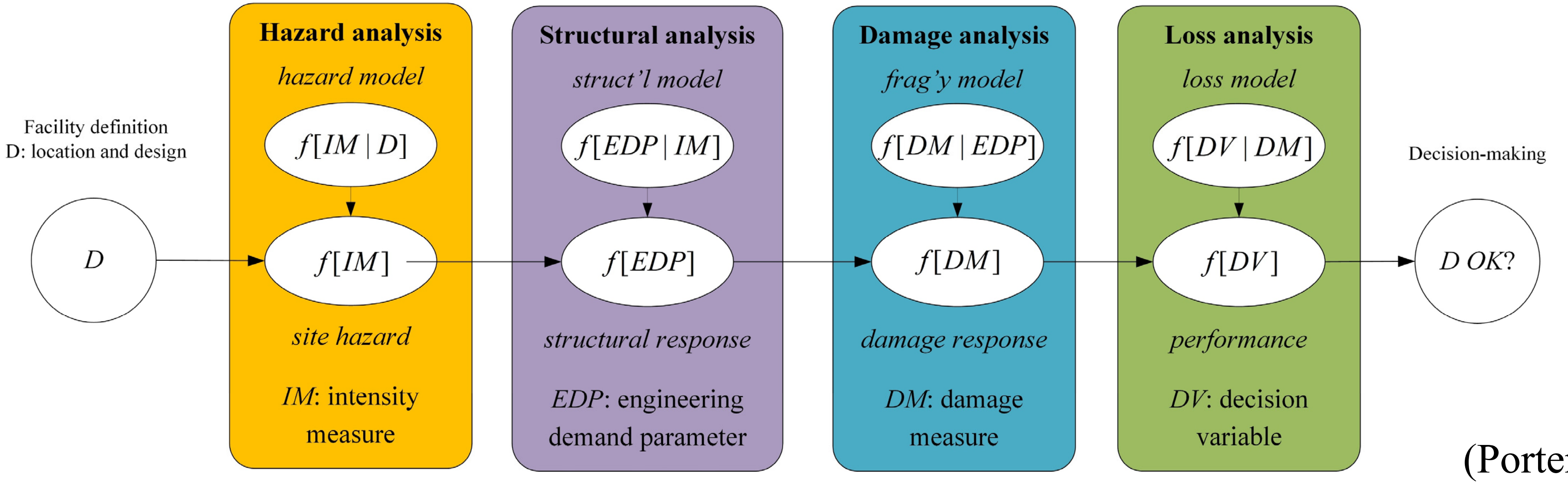
Outline

- **Existing Performance-Based Engineering Frameworks**
- **Proposed Performance-Based Multihazard Framework**
- **Capability of the Extended Framework**
- **Application Example**
- **Conclusions**
- **Future Work**

Performance-Based Earthquake Engineering (PBEE) Framework



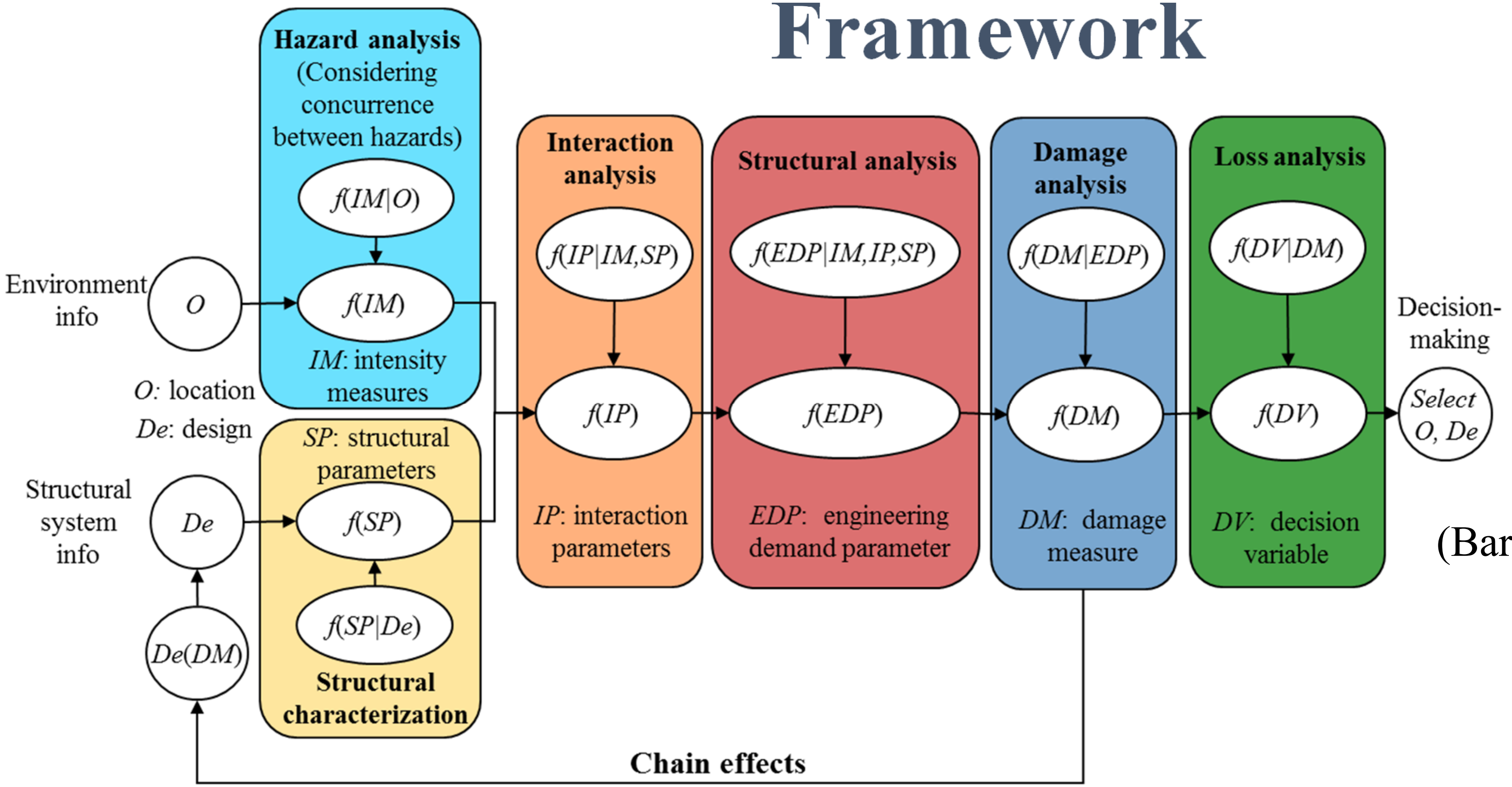
(Porter, 2003)

$$G(DV) = \iiint G(DV \mid DM) \cdot f(DM \mid EDP) \cdot f(EDP \mid IM) \cdot dDM \cdot dEDP \cdot dIM$$

$G(\cdot)$ = complementary cumulative distribution functions, and $G(\cdot \mid \cdot)$ = conditional complementary cumulative distribution function;
$f(\cdot)$ = probability density function, and $f(\cdot \mid \cdot)$ = conditional probability density function; DV = decision variable,
DM = vector of damage measures; EDP = vector of engineering demand parameters; IM = vector of intensity measures;

[1] Porter, K.A. (2003) An Overview of PEER's Performance-Based Earthquake Engineering Methodology

Performance-Based Hurricane Engineering (PBHE) Framework



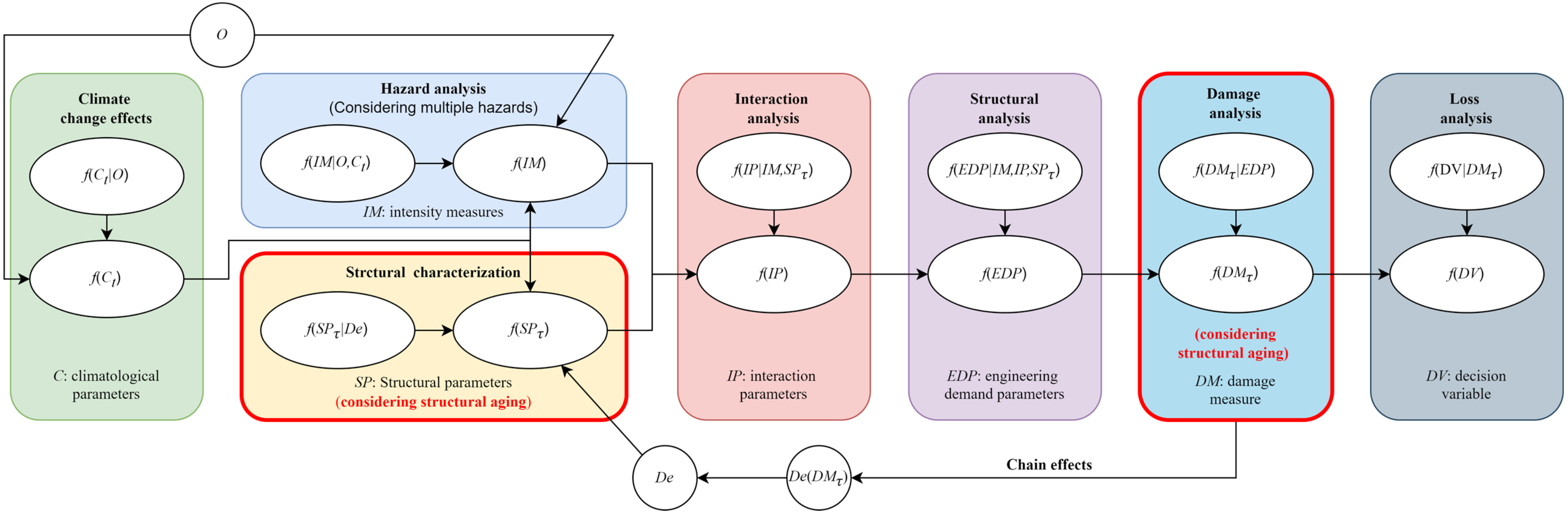
(Barbato et al., 2013)

$$G(DV) = \int\int\int\int\int G(DV \mid DM) \cdot f(DM \mid EDP) \cdot f(EDP \mid IM, IP, SP) \cdot f(IP \mid IM, SP)$$
$$\cdot f(IM) \cdot f(SP) \cdot \mathrm{d}\,DM \cdot \mathrm{d}\,EDP \cdot \mathrm{d}\,IP \cdot \mathrm{d}\,IM \cdot \mathrm{d}\,SP$$

IP = vector of interaction parameters; SP = vector of structure parameters;

[2] Barbato et al. (2013) Performance-Based Hurricane Engineering (PBHE) framework

Proposed PBME Framework



$$G(DV)=\iiint\!\!\!\iiint G(DV_{t,\tau}\,|\,DM_\tau)\cdot f(DM_\tau\,|\,EDP,C_t)\cdot f(EDP\,|\,IM,IP,SP_\tau)\cdot f(IP\,|\,IM,SP_\tau)$$
$$\cdot f(IM\,|\,C_t)\cdot f(SP_\tau\,|\,C_t)\cdot f(C_t)\cdot dDM_\tau\cdot dEDP\cdot dIM\cdot dIP\cdot dSP_\tau\cdot dC_t$$

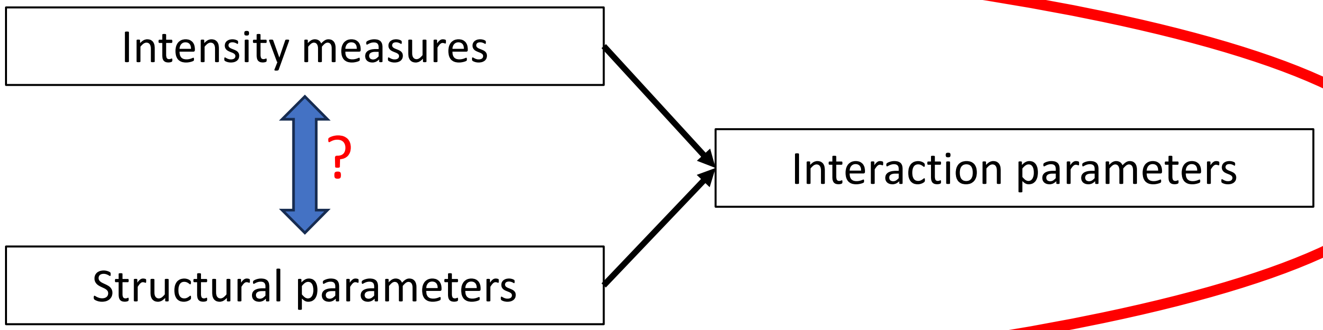
C_t = climatological parameters;
τ = structural time scale; t = global time scale

[3] Esmaeili (2022) Evaluation of the Effects of Climate Change on Hurricane-Induced Losses for Residential Buildings

Capabilities of the Extended Framework

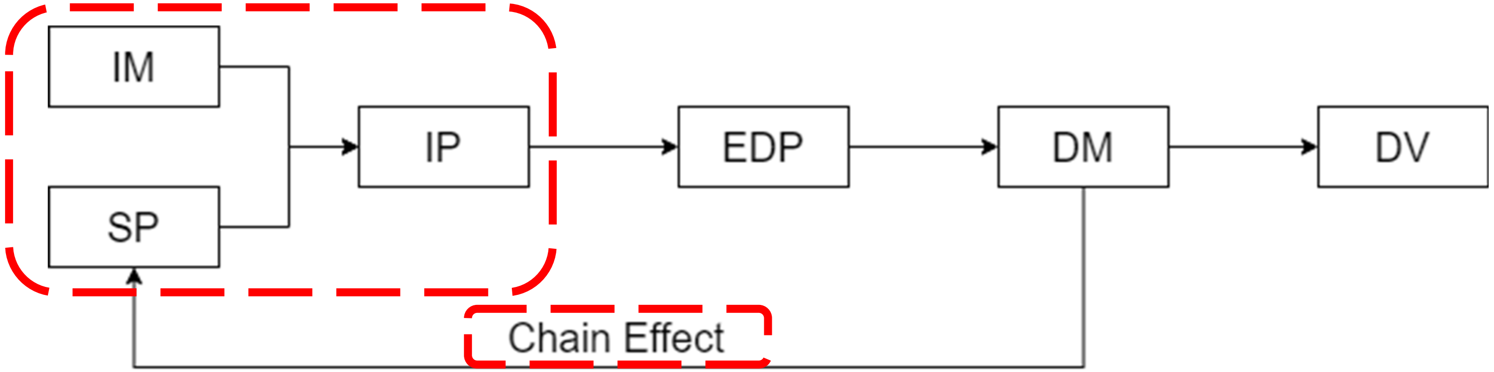
Single hazard:

- Separating the IM and SP allows considering the effects of structural parameters on the loading
- Chain effects



Multiple hazards:

- Capable to model multiple correlated/uncorrelated, synchronous/asynchronous hazards



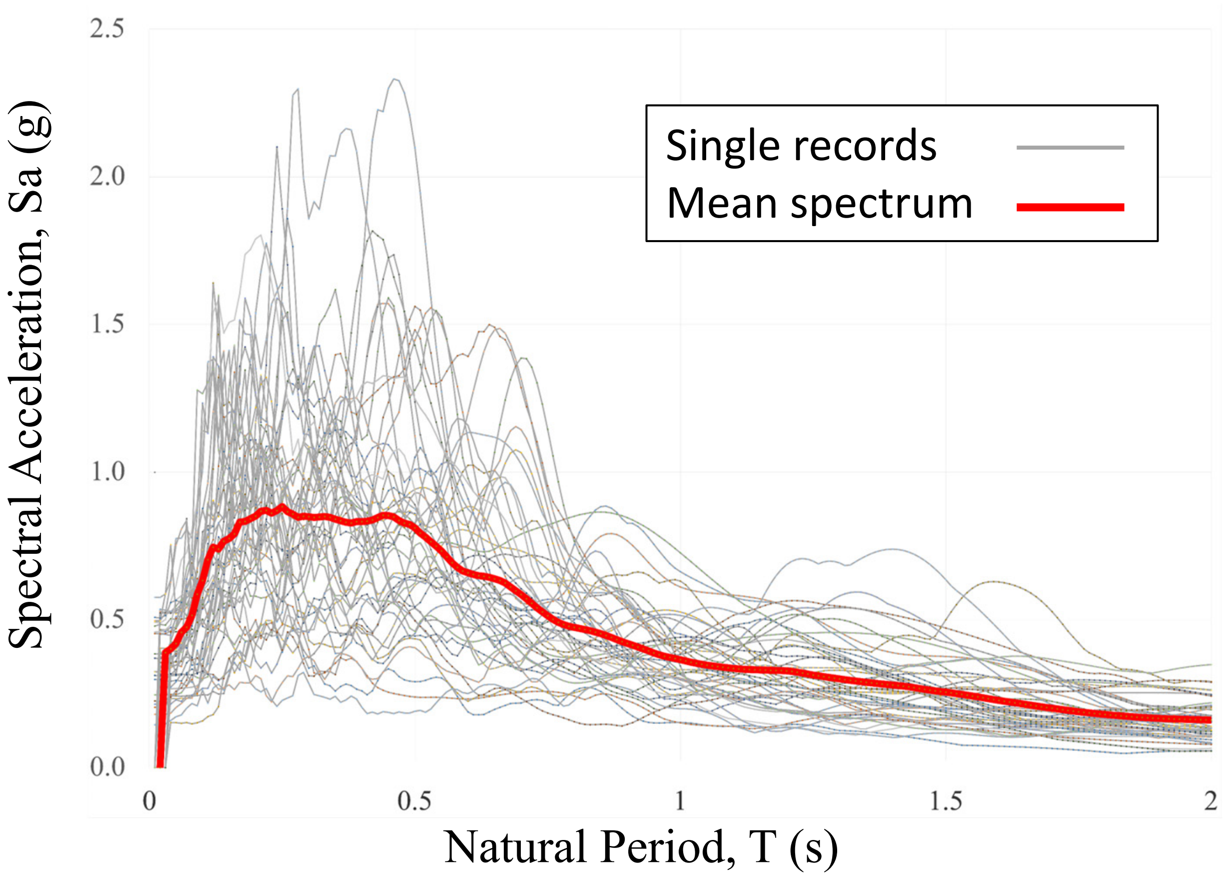
Climate change effects

Structural aging effects

Earthquake Records Selection

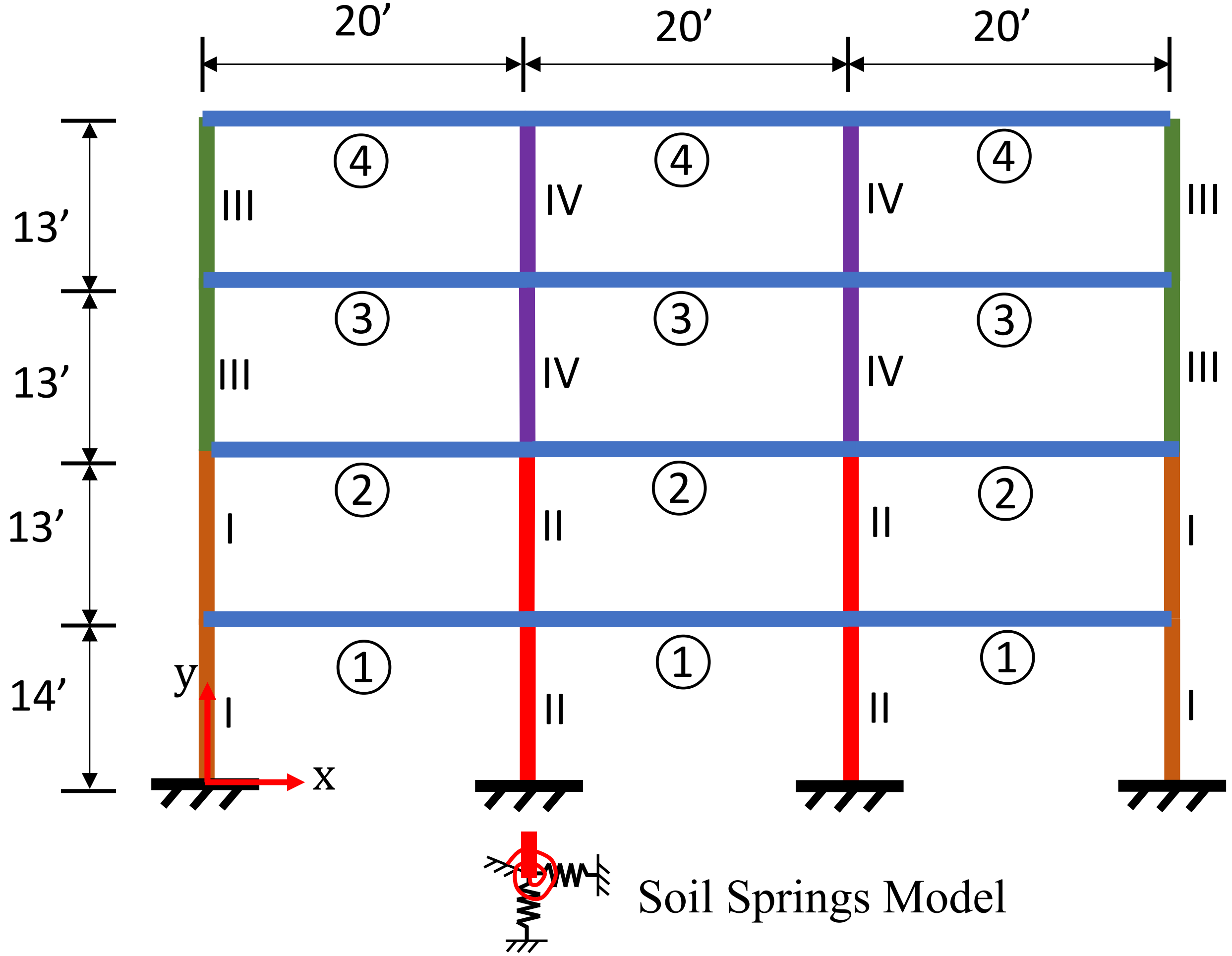
ID No.	Earthquake			Recording Station
	M	Year	Name	Name
1	6.7	1994	Northridge	Beverly Hills - Mulhol
2	6.7	1994	Northridge	Canyon Country - WLC
3	7.1	1999	Duzce, Turkey	Bolu
4	7.1	1999	Hector Mine	Hector
5	6.5	1979	Imperial Valley	Delta
6	6.5	1979	Imperial Valley	El Centro Array #11
7	6.9	1995	Kobe, Japan	Nishi - Akashi
8	6.9	1995	Kobe, Japan	Shin - Osaka
9	7.5	1999	Kocaeli, Turkey	Duzce
10	7.5	1999	Kocaeli,Turkey	Arcelik
11	7.3	1992	Landers	Yermo Fire Station
12	7.3	1992	Landers	Coolwater
13	6.9	1989	Loma Prieta	Capitola
14	6.9	1989	Loma Prieta	Gilroy Array #3
15	7.4	1990	Manjil, Iran	Abbar
16	6.5	1987	Superstition Hills	El Centro Imp. Co.
17	6.5	1987	Superstition Hills	Poe Road (temp)
18	7.0	1992	Cape Mendocino	Rio Dell Overpass
19	7.6	1999	Chi-Chi, Taiwan	CHY101
20	7.6	1999	Chi-Chi, Taiwan	TCU045
21	6.6	1971	San Fernando	LA - Hollywood Stor
22	6.5	1976	Friuli, Italy	Tolmezzo

Normalized & Mean Spectra



Benchmark Example (1)

Structural Systems



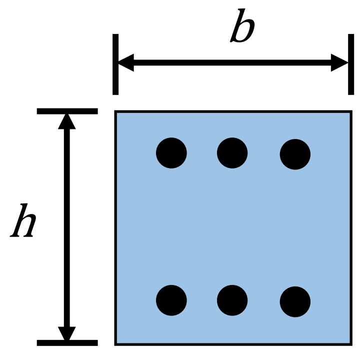
2D 4 story Reinforced Concrete Building

	h (in)	b (in)	ρ_l	ρ_t	s (in)
Column I	22	22	0.0130	0.0070	5.0
Column II	22	22	0.0163	0.0070	5.0
Column III	22	22	0.0113	0.0070	5.0
Column IV	22	22	0.0145	0.0070	5.0
Beam 1	24	22	0.0126	0.0033	5.0
Beam 2	24	22	0.0112	0.0033	5.0
Beam 3	24	22	0.0092	0.0033	5.0
Beam 4	24	22	0.0077	0.0033	5.0

ρ_l: longitudinal steel reinforcement ratio

ρ_t: transverse steel reinforcement ratio

s: spacing between stirrups



[4] Haselton (2007) Assessing Seismic Collapse Safety of Modern Reinforced Concrete Moment-Frame Buildings

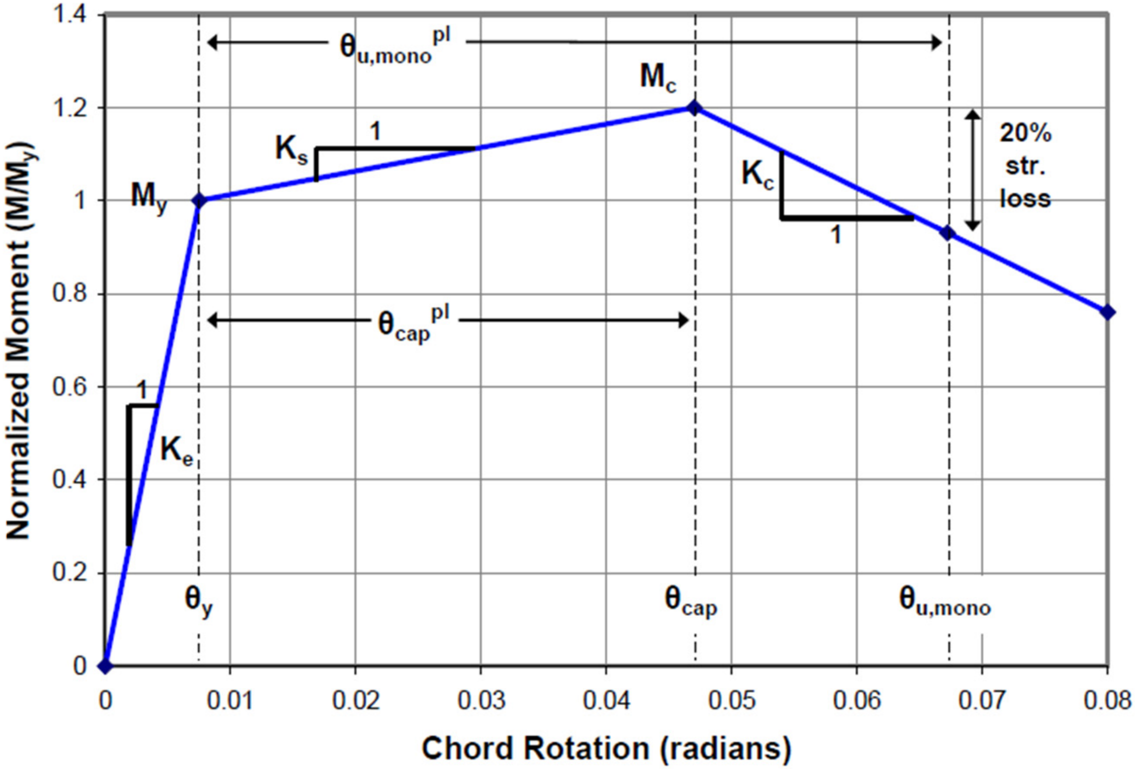
Benchmark Example (2)

Structural Uncertainty

	Variable	Distribution	Mean	St. D.
Material Uncertainty	E_{steel}	Normal	29200	964
	f_y	Beta	60	6
	f'_c	Lognormal	5	1
	E_{conc}	Normal	4030	0.086
Soil Spring Uncertainty	Horizontal	Normal	924	277
	Vertical	Normal	15840	4752
	Rotational	Normal	4752000	1425600

	Variable	Distribution	Eqn	σ_{LN}
Hinge Uncertainty	M_y	Normal	(6)[5]	0.2*
	EI_{stf}	Lognormal	(4.3)[4]	0.33
	θ_{cap}	Lognormal	(4.15)[4]	0.54
	θ_{pc}	Lognormal	(4.17)[4]	0.72
	M_c/M_y	Lognormal	(4.18)[4]	0.1
	λ	Lognormal	(4.19)[4]	0.49

Plastic Hinge Model for Collapse Simulation



St. D.: Standard Deviation

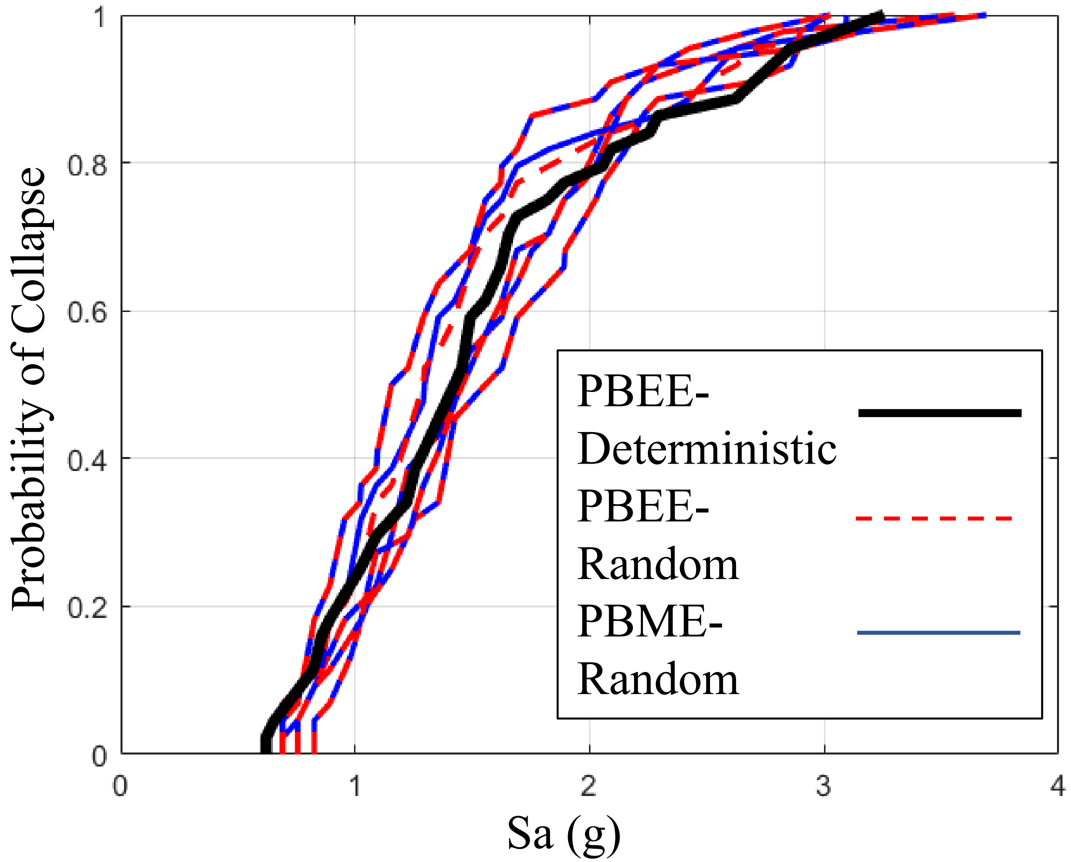
*: standard deviation

[4] Haselton (2007) Assessing Seismic Collapse Safety of Modern Reinforced Concrete Moment-Frame Buildings

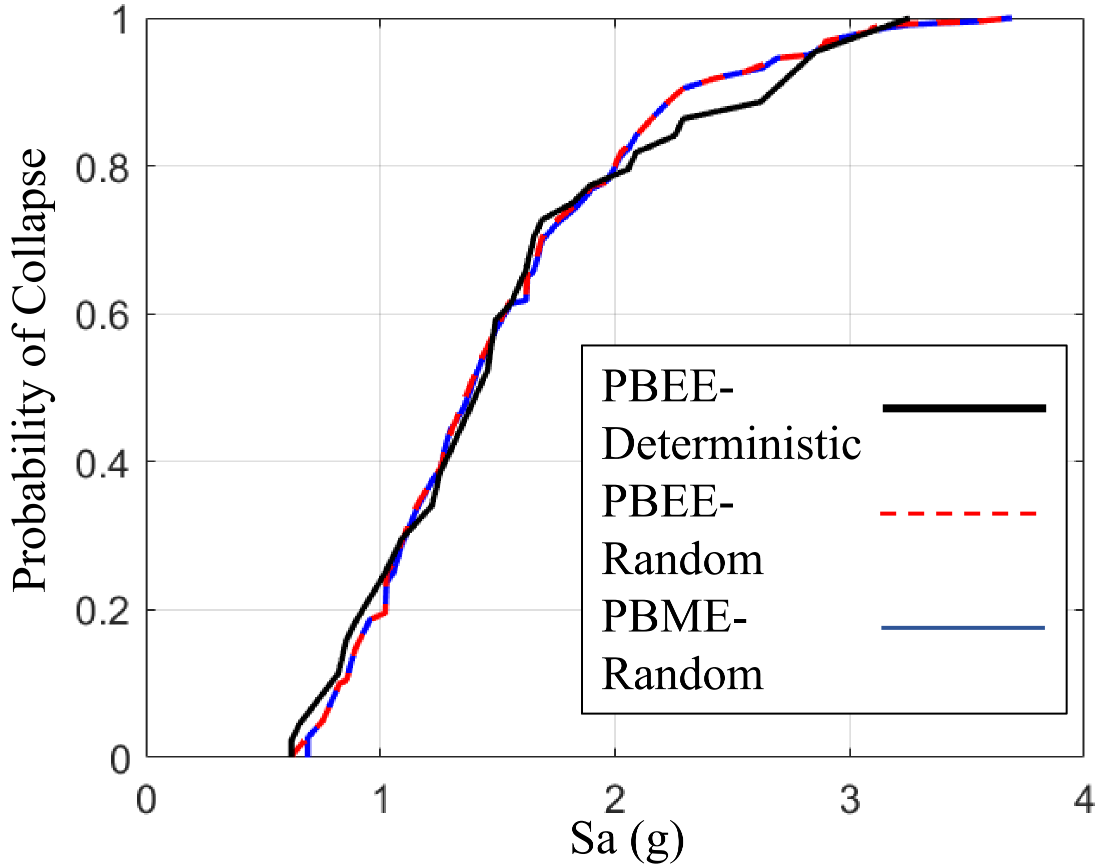
[5] Apanagiotakos & Fardis (2001) Deformations of Reinforced Concrete Members at Yielding and Ultimate

Results for Fixed-Based Model

Individual IDAs



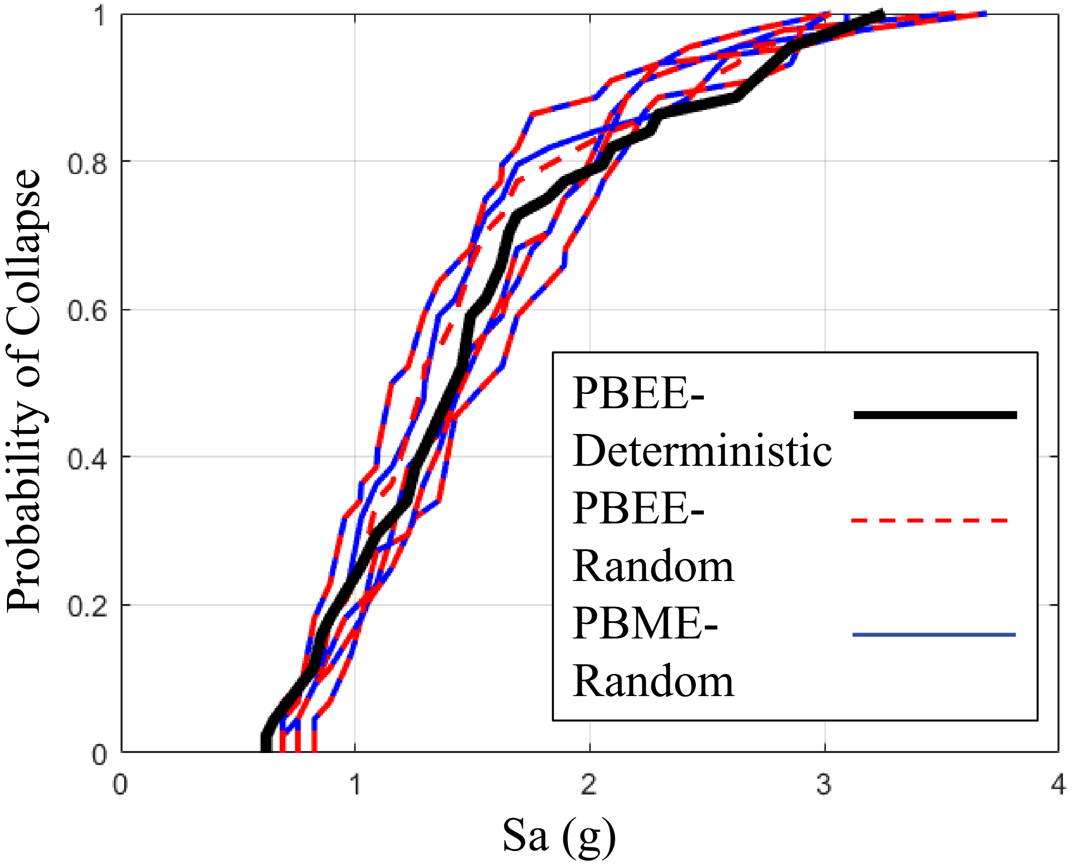
Comparison ECDF Median



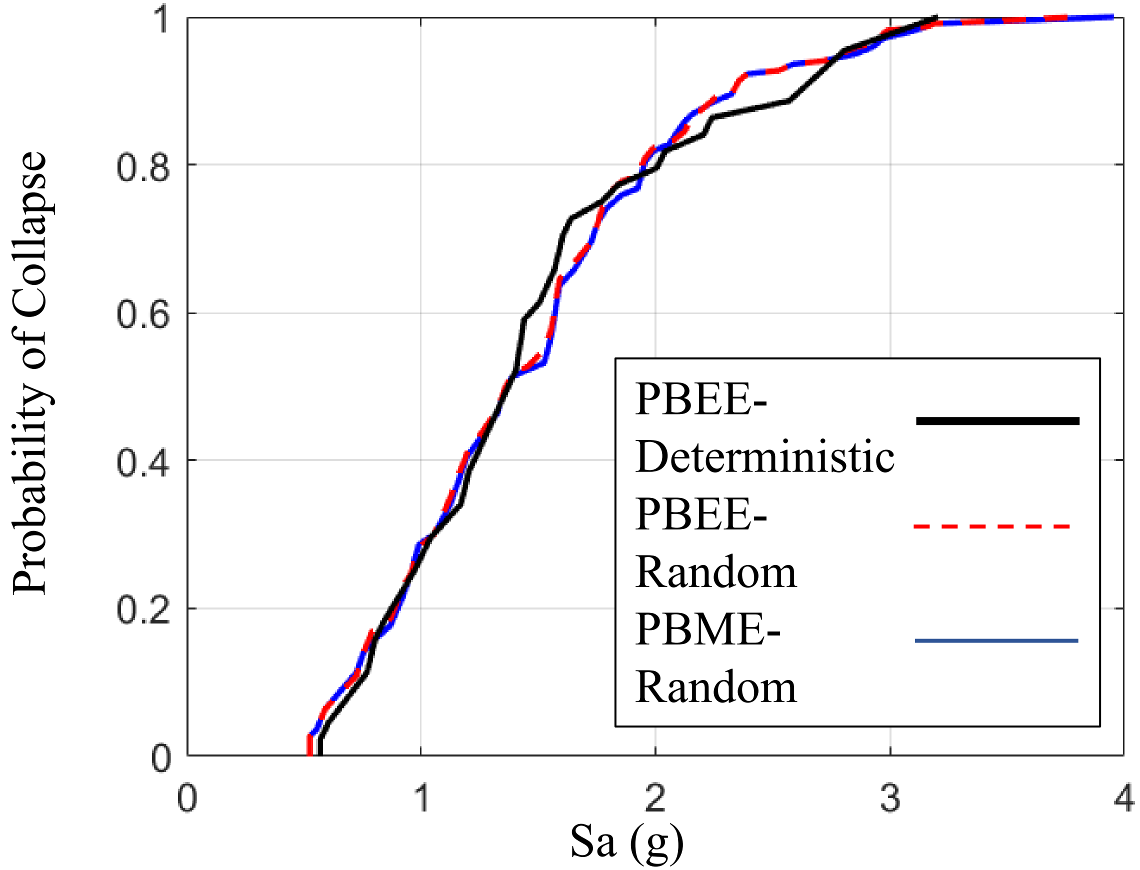
Fixed-Base Model	PBEE-D	PBEE-R	PBME-R
Median Collapse Sa (g)	1.4550	1.4900	1.4900
Beta	0.4151	0.4120	0.4103

Results for Soil Springs Model

Individual IDAs



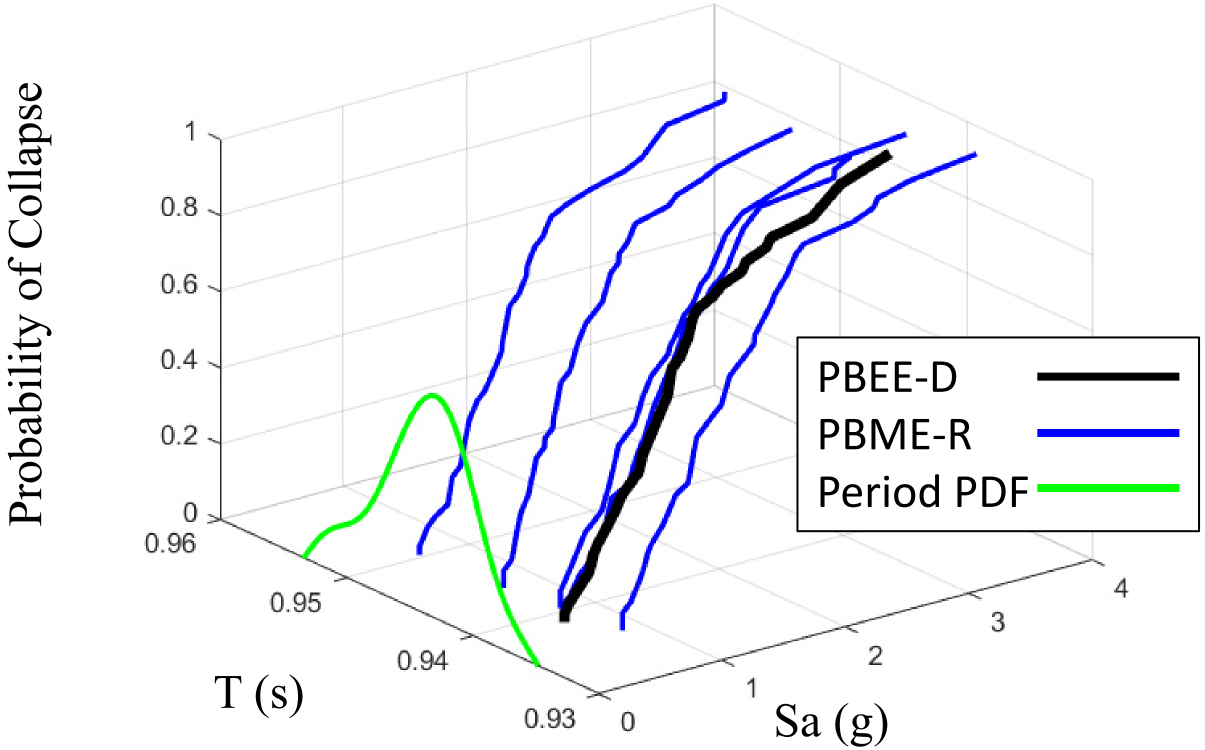
Comparison ECDF Median



Soil Springs Model	PBEE-D	PBEE-R	PBME-R
Median Collapse Sa (g)	1.4050	1.3900	1.3900
Beta	0.4311	0.4460	0.4445

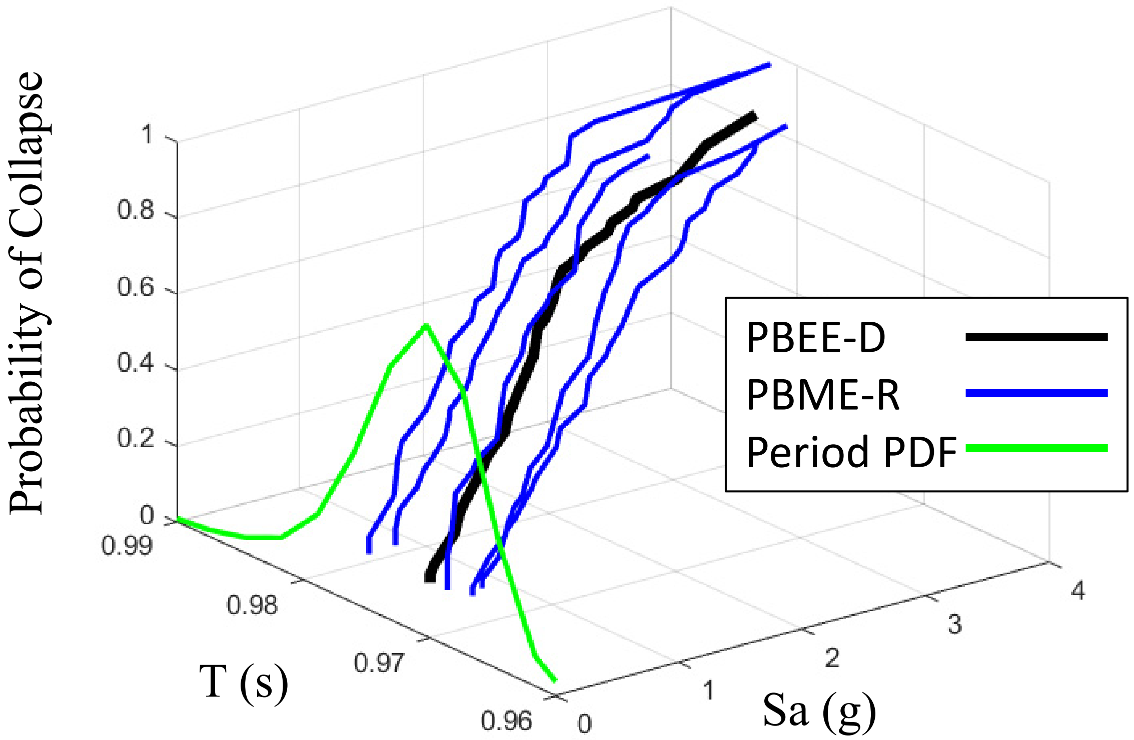
Effect of Natural Period Variability

ECDF & Period Distribution for Fixed-Base Model



Mean T (s)	**0.941**
St. D. T (s)	0.009

ECDF & Period Distribution for Soil Springs Model



Mean T (s)	**0.974**
St. D. T (s)	0.016

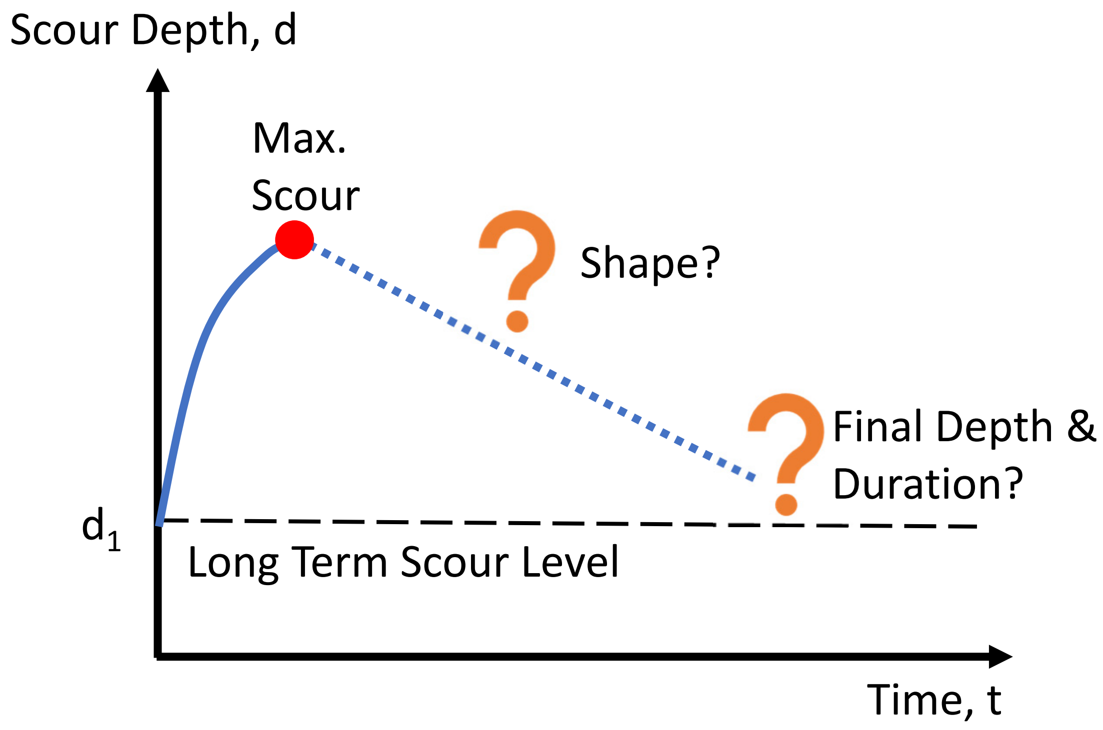
Conclusions

- We have proposed a PBME framework that is consistent with PBEE
- PBME allows to account for multiple items that would require ad-hoc modification of PBEE
- For the example considered here, the effects of natural period variability due to structural uncertainty are negligible
- Additional work is needed to assess if this is a general result, as well as additional properties of the proposed PBME framework

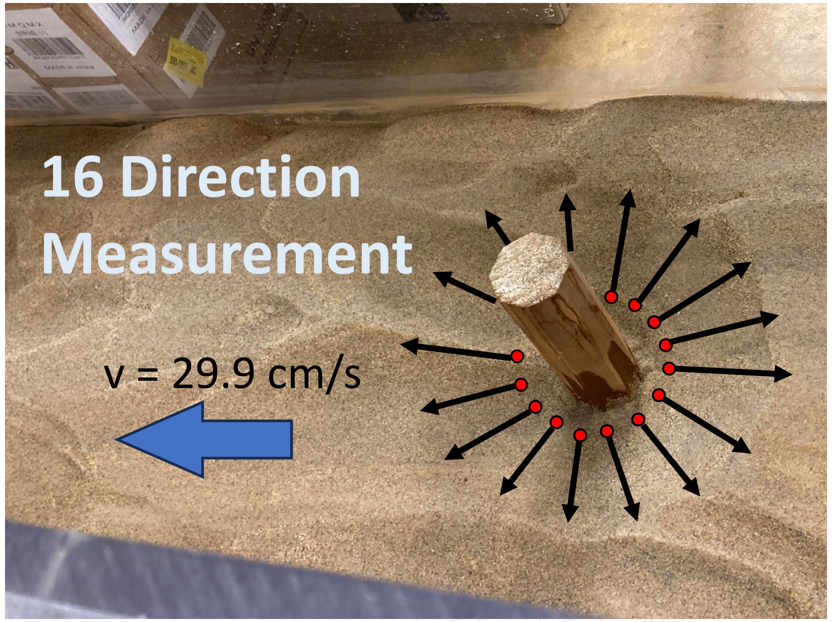
Future Work

- Investigate the proposed framework for other cases
- Implement and assess the proposed framework considering multiple hazards, e.g., scour and seismic actions

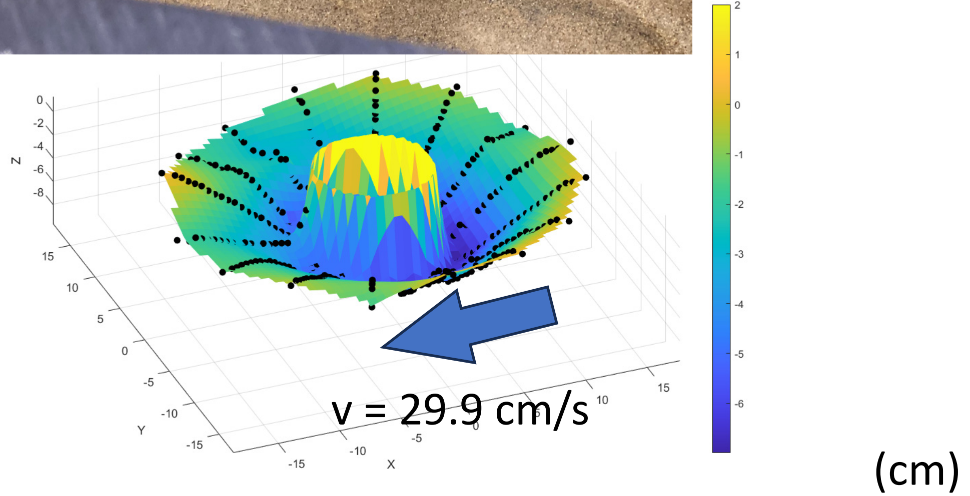
Seismic and Scour Analysis (1)



Scour and Recovery Time History



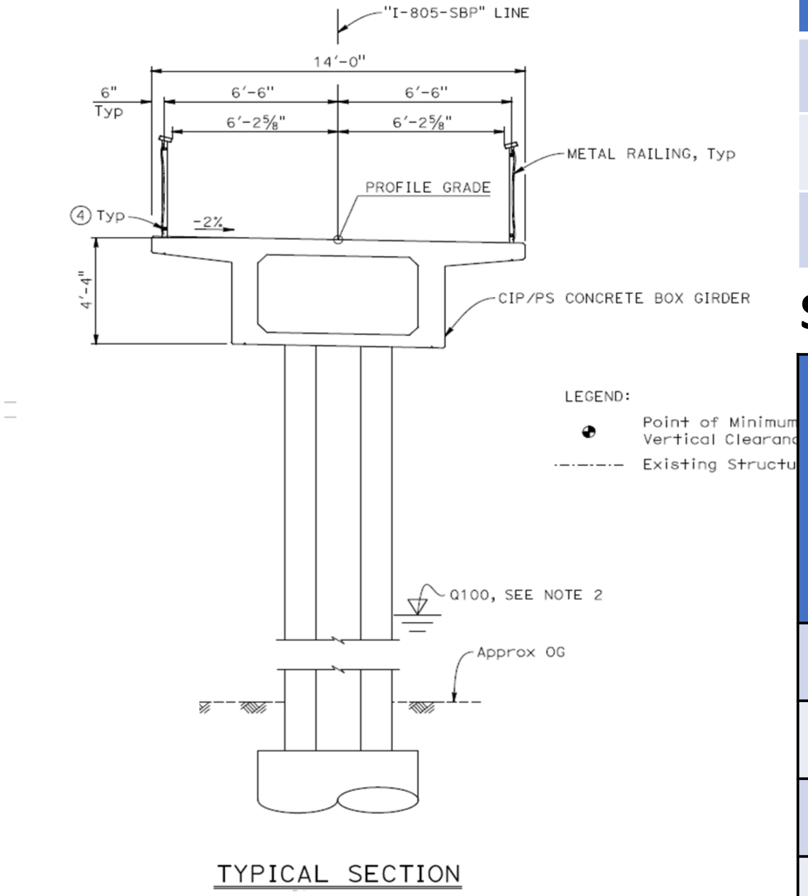
Experimental Scour Depth Measuring



3D Scour Modeling

Seismic and Scour Analysis (2)

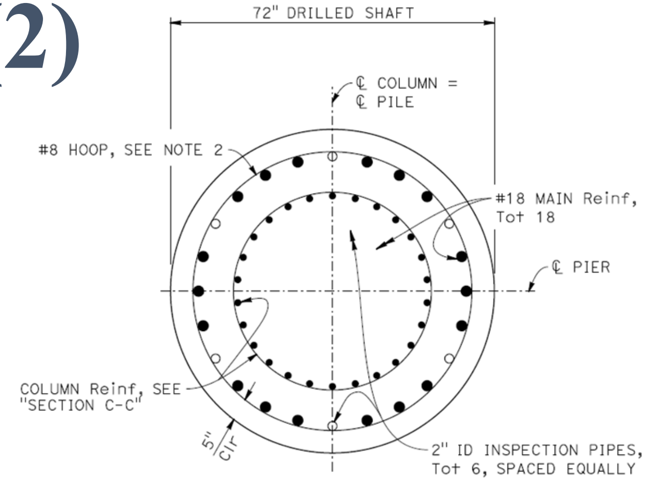
Example: Otay River Bike Bridge



Bridge Typical Section

Discharge:

Flood Event	Peak Discharge (cfs)
Q-50	12,000
Q-100	22,000
Q-200	29,000



Pier Cross Section

Scour Information:

Substructure Component	Short-Term Scour Depths	Long-Term Scour Depths		Total Scour Depth (ft)
	Local Scour (ft)	Degradation (ft)	Contraction Scour (ft)	
Abutment 1	0.00	0.00	0.00	0.00
Pier 2	8.60	0.00	2.31	10.91
Pier 3	6.82	0.00	2.31	9.13
Pier 4	7.59	0.00	2.31	9.90
Abutment 5	0.00	0.00	0.00	0.00

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Thank you very much!

Questions?

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