Nonlinear Site Response & Revisions to NEHRP/ASCE Site Factors

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NGA WEST 2

Pacific Earthquake Engineering Research Center

NGA west 2

Contributors

NGA-West 2, Task 8

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Outline

- Semi-empirical site amplification model
- Development of NEHRP factors
- Conclusions

Semi-Empirical Model

- Motivations:
  - Task 8 committee found discrepancies between NEHRP and original NGA site factors
  - Site amplification model developed to guide evaluation of revised NEHRP factors
  - Provide insights regarding GMPE site functions
- Incorporates NGA-West2 data and 1D simulations
- NEHRP proposal developed based on model (tabulated factors & equations)

Data Selection Criteria

- July 2012 flatfile. 8611 records. 346 events
- Minimum of 10 records / event
- Data with $R_{jb} < 100$ km only
- Records omitted having unknown ground motions, **M**, R, or V_{s30}

Site Model

- Consider GMPE for rock site conditions (V_{s30}=760 m/s). iCB & BSSA
- Misfits expected for recordings on soil
- Compute residuals between data and rock GMPE

$$R_{ij} = \ln\left(IM_{obs}\right)_{ij} - \left[\left(\mu_r\right)_{ij} + \eta_i\right]$$

- Construct a site amplification model to remove trends with site parameters

Model Summary

- ***Combined model***

$$\ln(F) = \ln(F_{lin}) + \ln(F_{nl})$$

- ***Linear term***

$$\ln(F_{lin}) = (c + \Delta c)\ln\left(\frac{V_{s30}}{V_{ref}}\right)$$

V_{ref} = 760 m/s
c = slope term for V_{s30}-scaling
Δc = regional correction

- ***Nonlinear term***

$$\ln(F_{nl}) = f_1 + f_2 \ln\left(\frac{PGA_r + f_3}{f_3}\right)$$

$f_2 = f(V_{s30}, PGA_r)$

f_3 = 0.1 g, $f_1 = 0$

Steps in Model Development

- Evaluation of nonlinearity. Guided by data trends and simulation results
- Evaluation of V_{s30}-scaling, including regional effects
- Analysis of residuals to check performance

Nonlinearity

- Data analysis

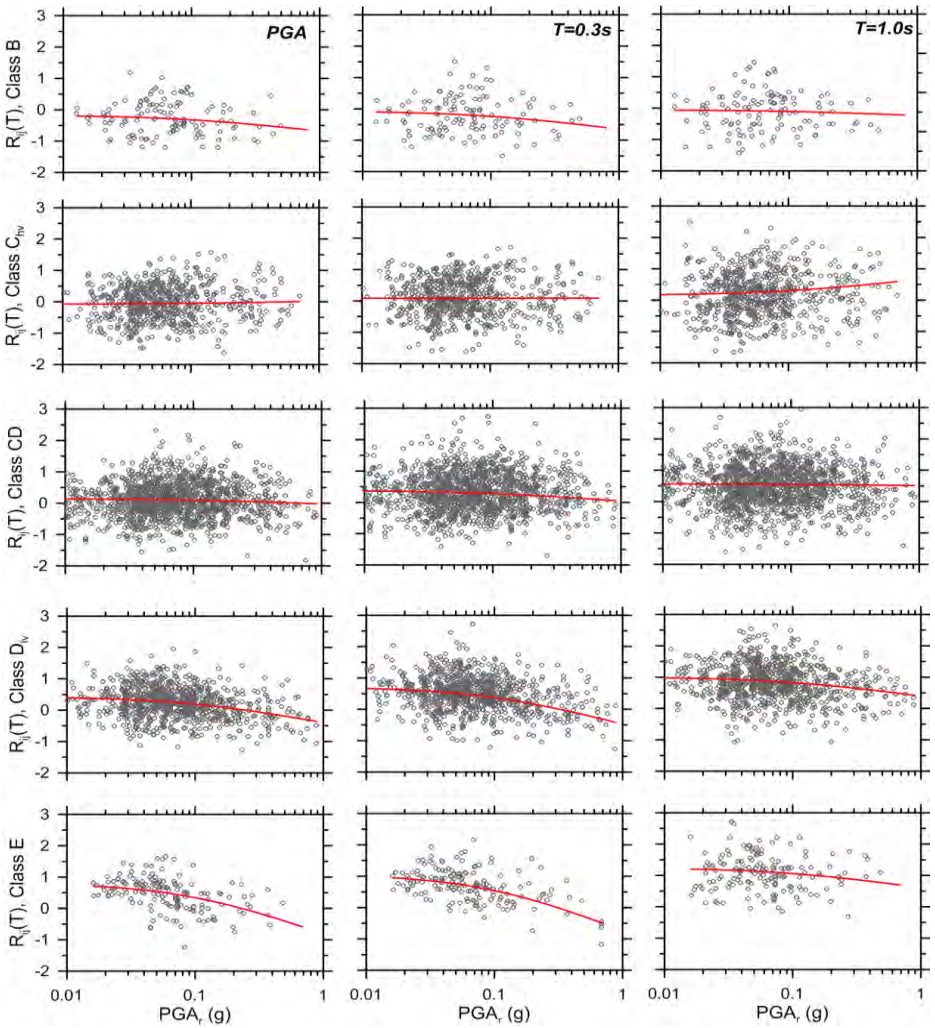
Bin residuals (R_{ij}) by V_{s30}:

$$Class\ B \quad : 760 < V_{s30} < 1500\ m/s$$
$$Class\ C_{hv} : 520 < V_{s30} < 760\ m/s$$
$$Class\ CD : 310 < V_{s30} < 520\ m/s$$
$$Class\ D_{lv} : 200 < V_{s30} < 310\ m/s$$
$$Class\ E \quad : 200 \geq V_{s30}\ m/s$$

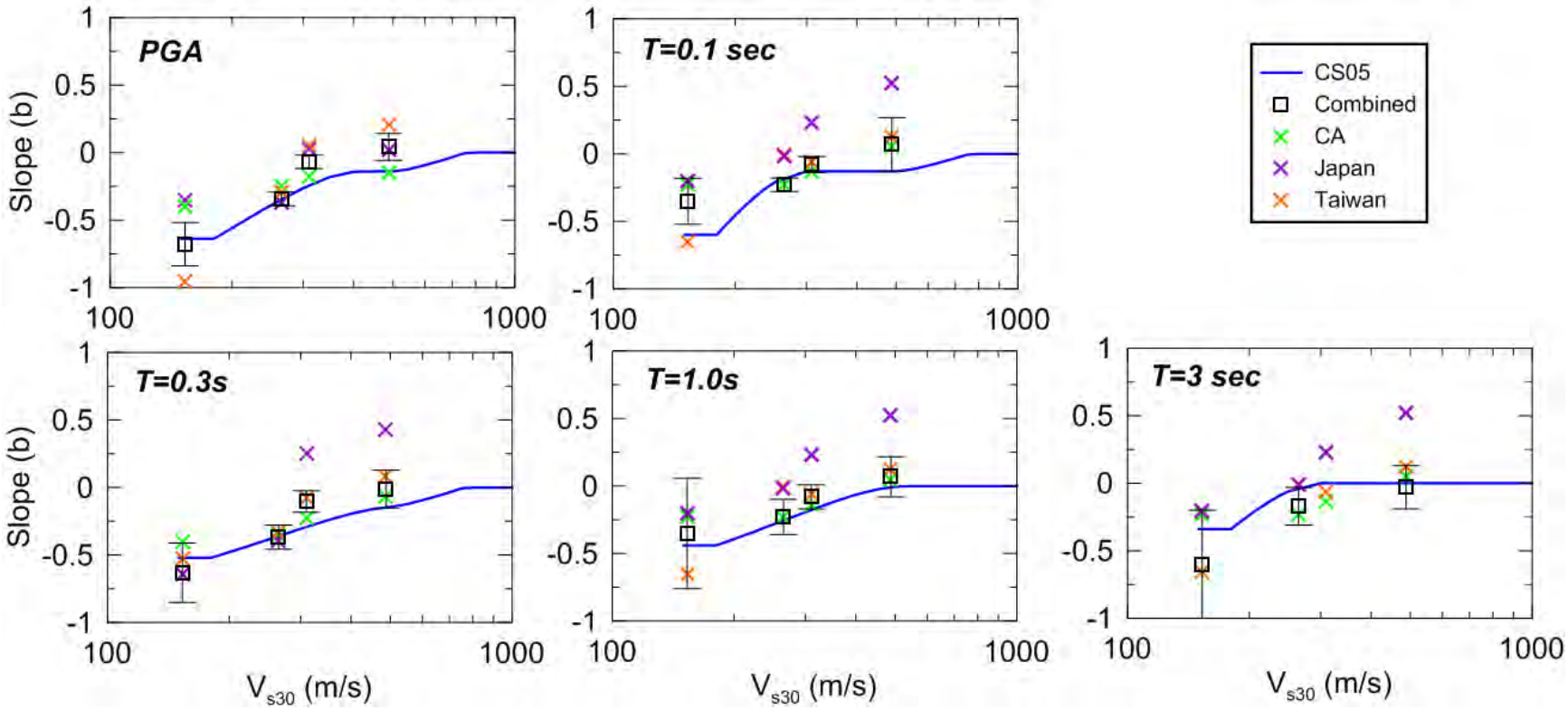
Plot against PGA_r

Nonlinear regression

$$R_i = a + b\ln\left(PGA_r + d\right)_i + \varepsilon_i$$



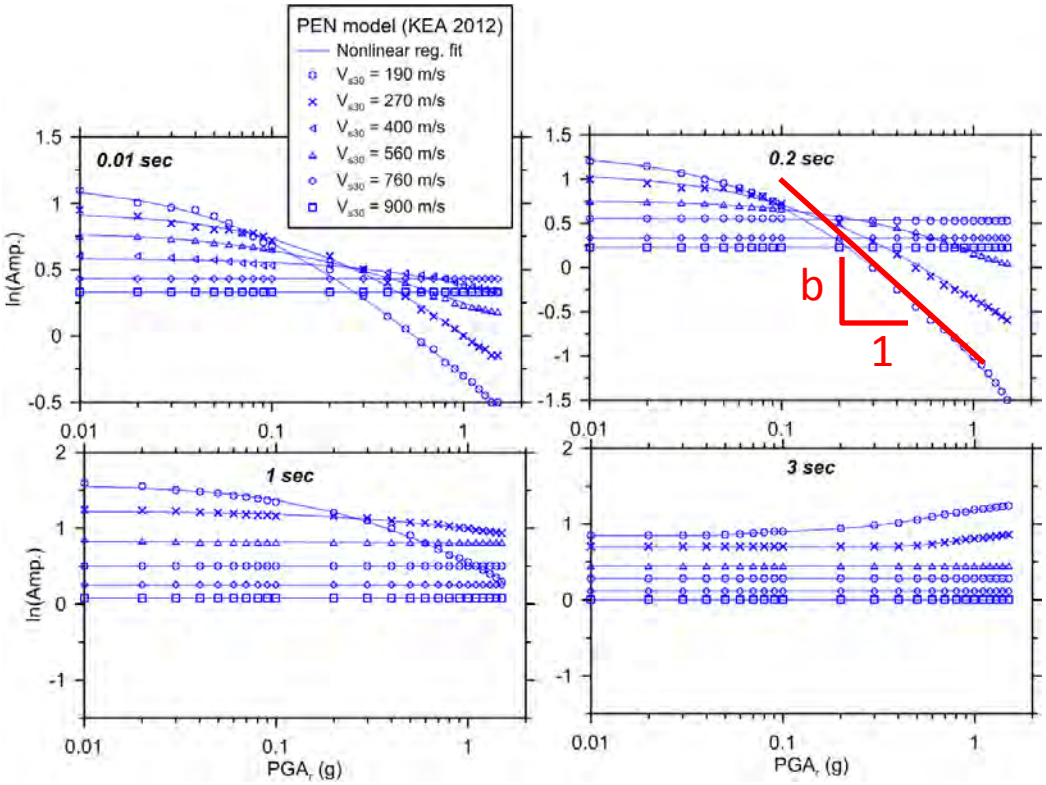
Nonlinearity



Nonlinearity

- Data analysis
- Interpretation of simulation results (Kamei et al., 2012)

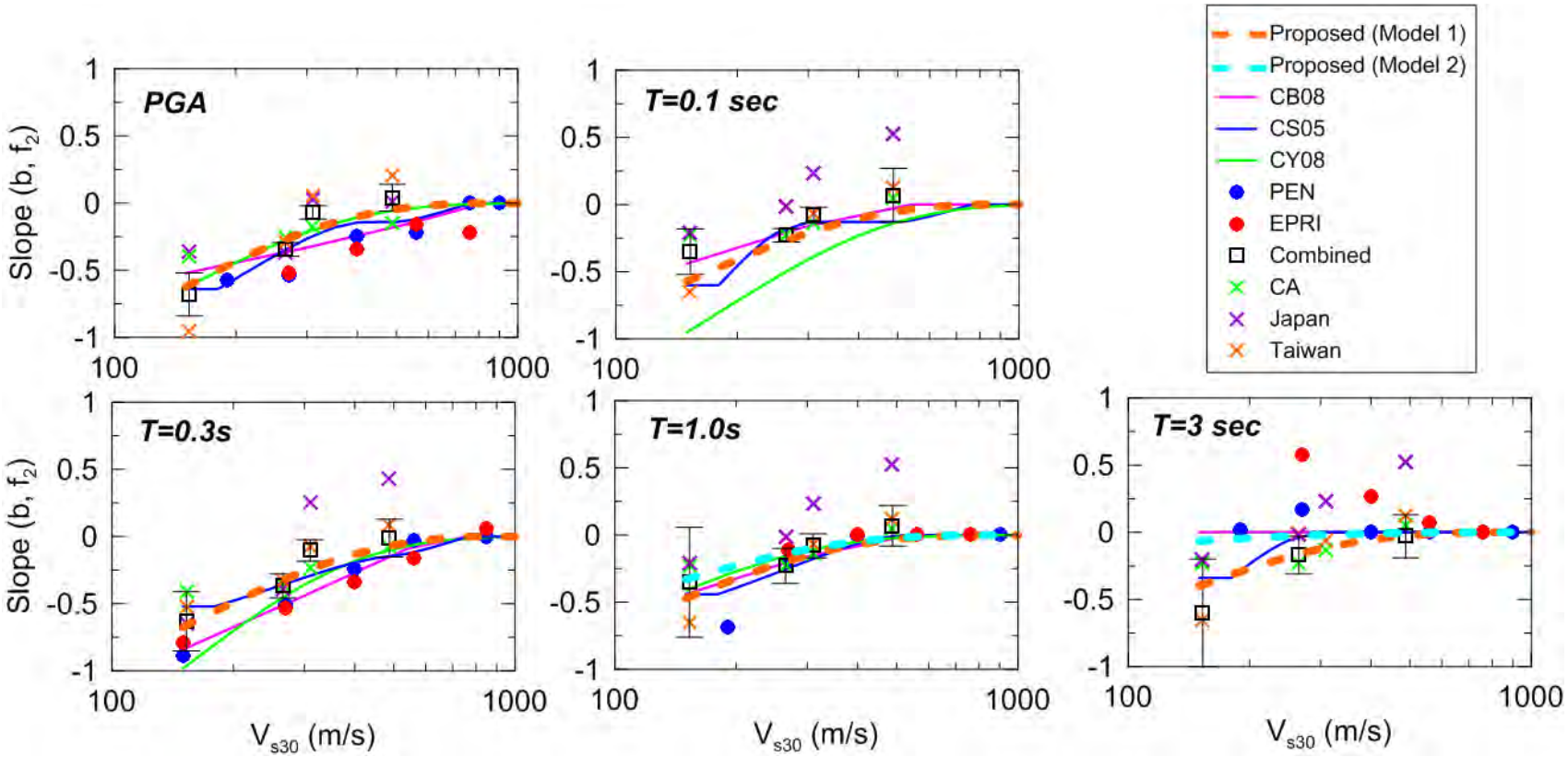
Fit slope parameter to simulation results



Nonlinearity

- Data analysis
- Interpretation of simulation results (Kamei et al., 2012)
- Plot b vs V_{s30} and select model that captures trends

Nonlinearity



V_{s30}-Scaling

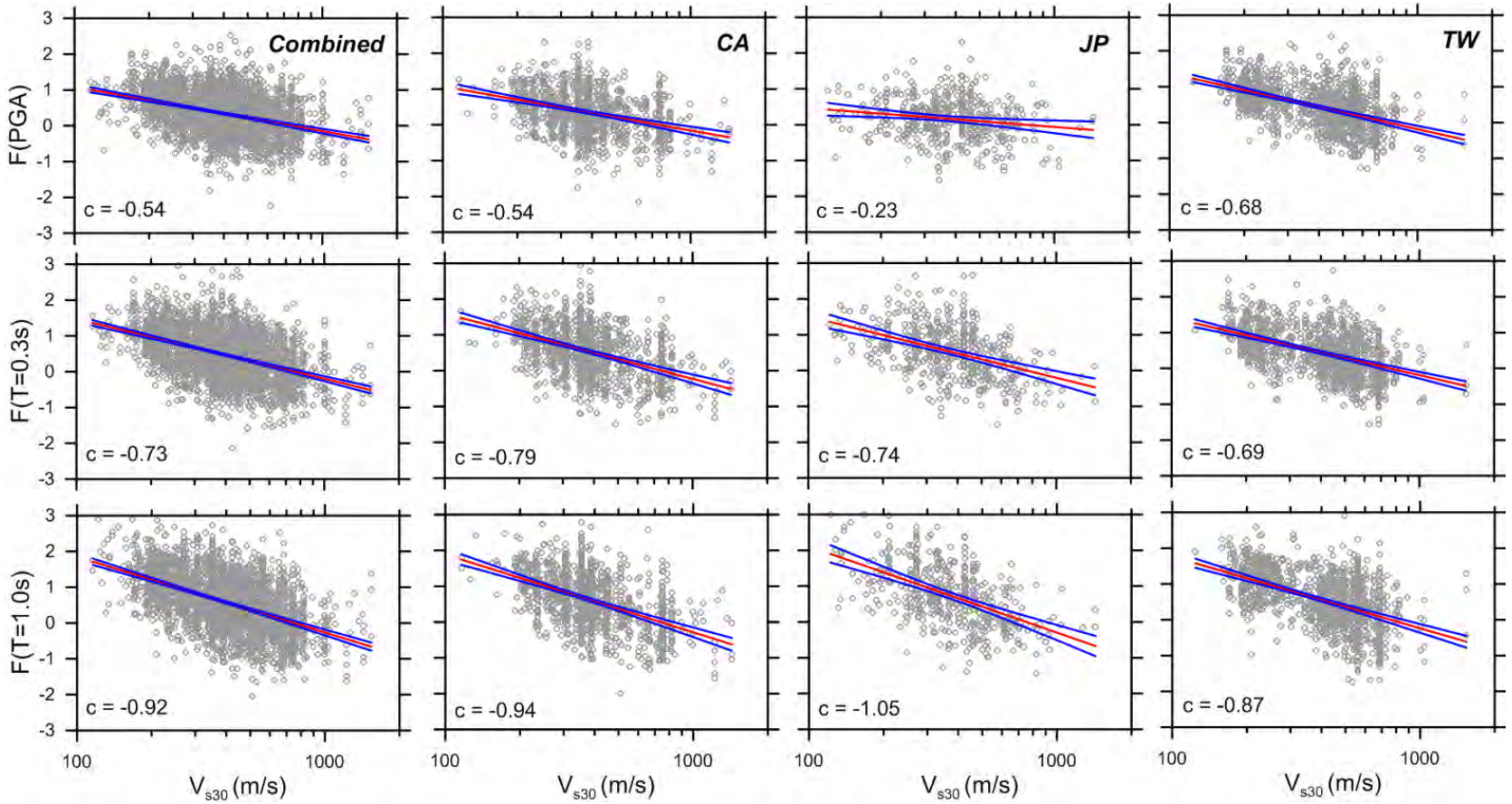
- Remove nonlinearity from residuals

$$R_k^{lin} = R_{i,j} - \ln(F_{nl})$$

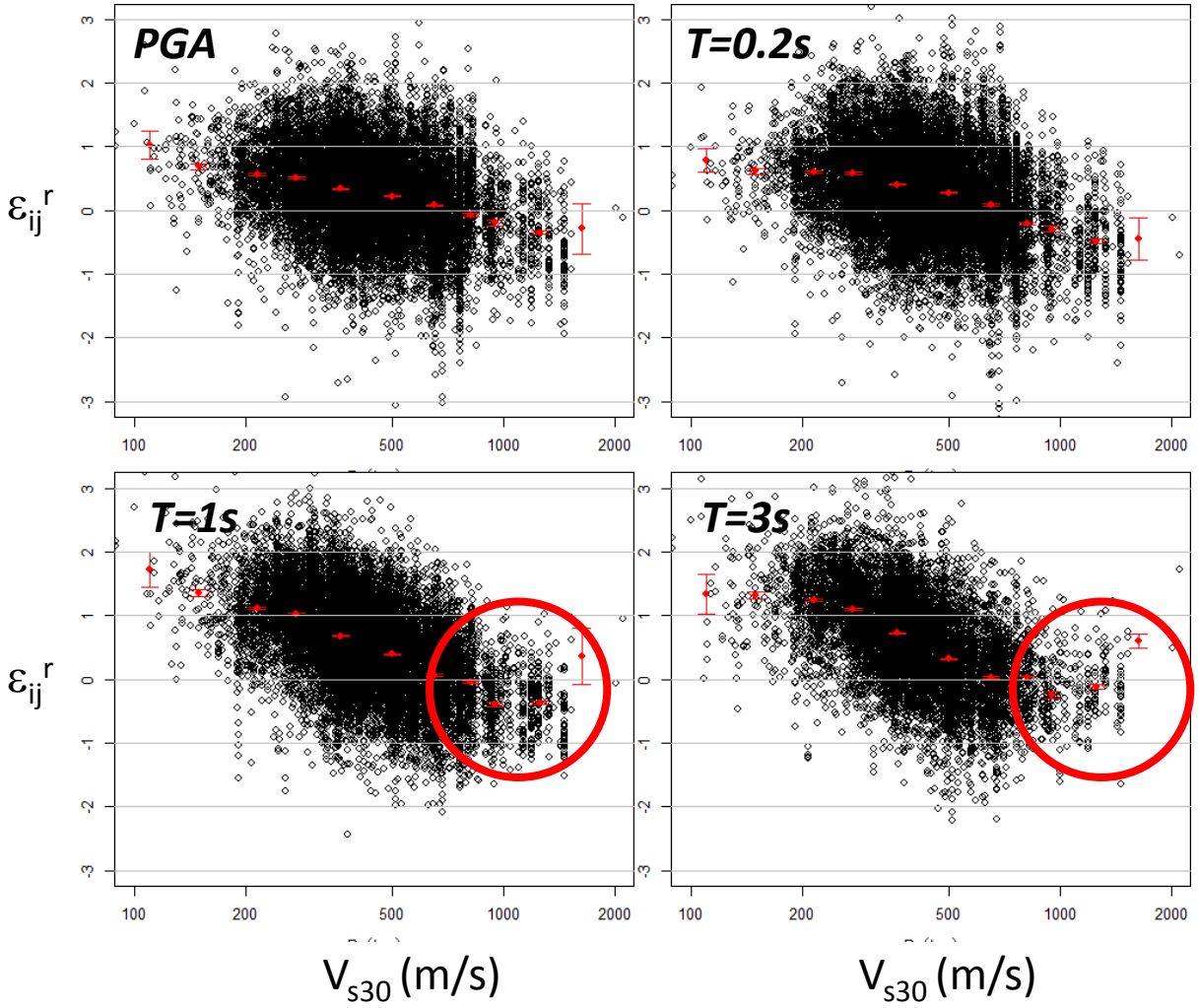
V_{s30}-Scaling

- Remove nonlinearity from residuals
- Plot adjusted residuals against V_{s30}, compute slope

V_{s30}-Scaling



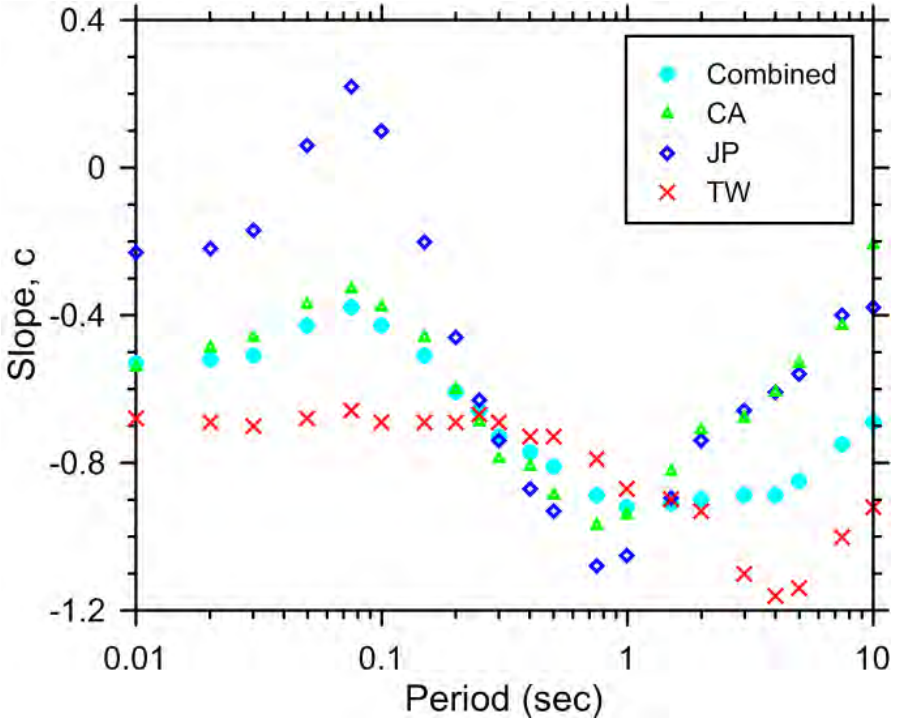
BSSA within-Event Rock Residuals



All data
C1 & C2
CR_{jb} 10 km

V_{s30}-Scaling

- Remove nonlinearity from residuals
- Plot adjusted residuals against V_{s30}, compute slope
- Regional variations in slope observed



V_{s30}-Scaling

- Remove nonlinearity from residuals
- Plot against V_{s30}, compute slope
- Regional variations in slope observed
- Parameter *c* set from combined data set, Δc from regional results

$$\ln(F_{lin}) = (c + \Delta c)\ln\left(\frac{V_{s30}}{V_{ref}}\right)$$

Period (sec)	*c*	*Δ c (CA)*	*Δ c (JP)*	*Δ c (TW)*
0.01	-0.53	-0.01	0.30	-0.15
0.02	-0.52	0.03	0.30	-0.17
0.03	-0.51	0.05	0.34	-0.19
0.05	-0.43	0.06	0.49	-0.25
0.075	-0.38	0.05	0.60	-0.28
0.1	-0.43	0.05	0.53	-0.26
0.15	-0.51	0.05	0.31	-0.18
0.2	-0.61	0.01	0.15	-0.08
0.25	-0.66	-0.03	0.03	-0.01
0.3	-0.73	-0.06	-0.01	0.04
0.4	-0.77	-0.04	-0.10	0.04
0.5	-0.81	-0.08	-0.12	0.08
0.75	-0.89	-0.08	-0.19	0.10
1	-0.92	-0.02	-0.13	0.05
1.5	-0.91	0.09	0.02	0.01
2	-0.90	0.19	0.16	-0.03
3	-0.89	0.21	0.23	-0.21
4	-0.89	0.28	0.28	-0.27
5	-0.85	0.32	0.29	-0.29
7.5	-0.75	0.32	0.35	-0.25
10	-0.69	0.48	0.31	-0.23

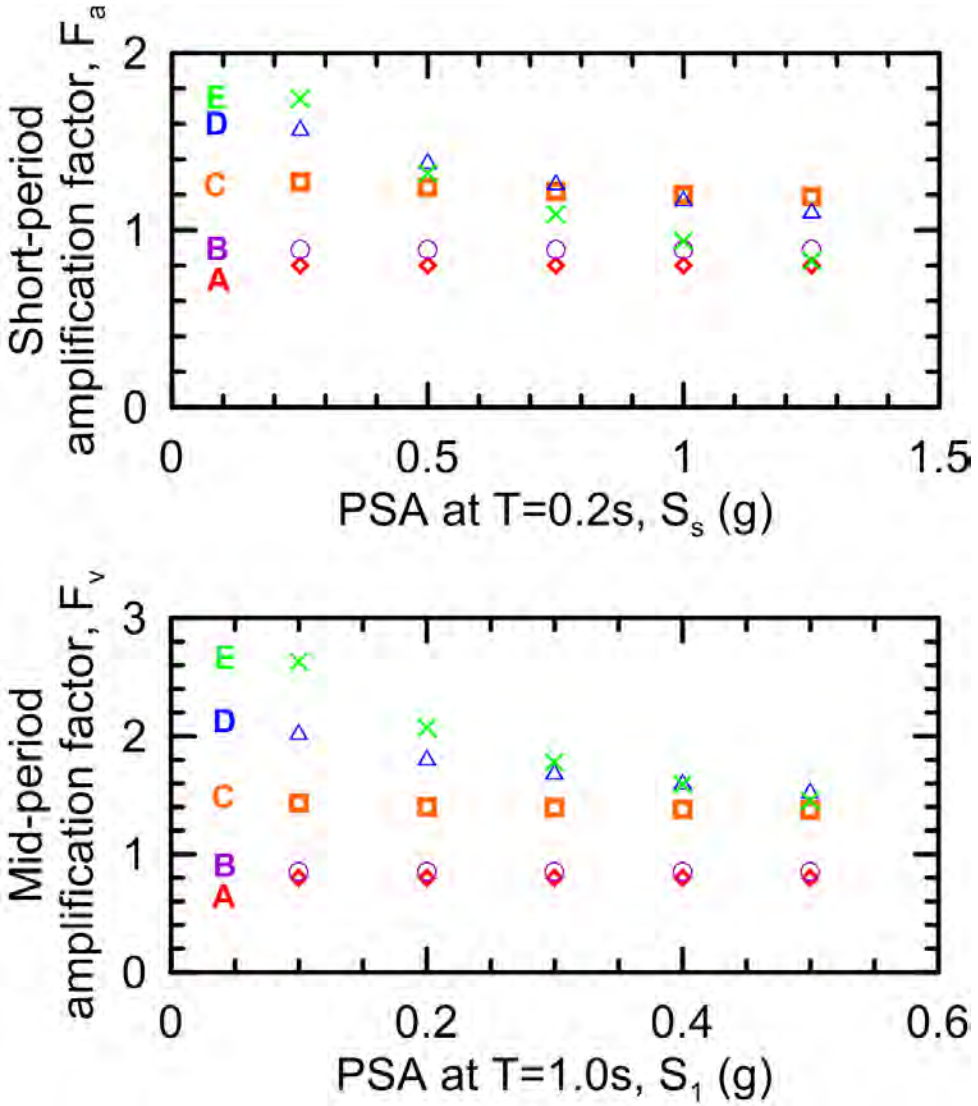
Outline

- Semi-empirical site amplification model
- **Development of NEHRP factors**
- Conclusions

NEHRP / ASCE Factors

- Extensive deliberations over > 2 years.
- Use V_{ref} = 760 m/s
- Use $\Delta c = 0$
- Select representative V_{s30} within categories
- Use mean values of f_2 across period ranges for F_a and F_v for each V_{s30}
- Convert PGA_r to S_s and S_1: $S_s \approx 2.3 \times PGA_r$ $S_1 \approx 0.7 \times PGA_r$
- Use mean values of c across period ranges

NEHRP / ASCE Factors



NEHRP / ASCE Factors

F_a

Site Class	S_s < 0.25		S_s = 0.5		S_s = 0.75		S_s = 1.0		S_s > 1.25	
	PEER	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*
A	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**
B	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**
C	1.3	**1.2**	1.2	**1.2**	1.2	**1.1**	1.2	**1.0**	1.2	**1.0**
D	1.6	**1.6**	1.4	**1.4**	1.3	**1.2**	1.2	**1.1**	1.1	**1.0**
E	1.7	**2.5**	1.3	**1.7**	1.1	**1.2**	0.9	**0.9**	0.8	**0.9**

F_v

Site Class	S_1 < 0.1		S_1 = 0.2		S_1 = 0.3		S_1 = 0.4		S_1 > 0.5	
	PEER	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*	*PEER*	*ASCE*
A	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**	0.8	**0.8**
B	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**	0.9	**1.0**
C	1.4	**1.7**	1.4	**1.6**	1.4	**1.5**	1.4	**1.4**	1.4	**1.3**
D	2.0	**2.4**	1.8	**2.0**	1.7	**1.8**	1.6	**1.6**	1.5	**1.5**
E	2.6	**3.5**	2.1	**3.2**	1.8	**2.8**	1.6	**2.4**	1.5	**2.4**

Formal proposal to PUC in Oct 2012 meeting

Conclusions

- Regional V_{s30} scaling in GMPEs
- NGA-West2 GMPEs will have nonlinear V_{s30}-based site terms
- Pending changes to NEHRP/ASCE site factors
  - V_{ref} set to 760 *m/s*
  - V_{s30}-scaling from global data
  - Reduced levels of nonlinearity (esp. C & D)
  - Final version likely to conservatively bound Class E factors