CENA Site Amplification

Based on work by:

NGA-East Geotechnical Working Group (Chair: Hashash)

USGS Expert Panel on CENA Site Amplification

Acknowledgments

- NGA-East Geotechnical Working Group
  - Chair: Hashash
  - Members: Campbell, Rathje, Silva, Stewart
  - Students and post docs: Chin, Harmon, Ilhan, Kim, Kottke, Parker
  - Other affiliated researchers
- Financial support from USGS ERP
- PEER NGA-East project (Goulet, Bozorgnia, et al.)
- Expert panel for CENA site amplification
  - Members: Atkinson, Boore, Darragh, Hashash, Silva, Stewart
  - Students: Harmon, Parker

Publications

Harmon, G, YMA Hashash, JP Stewart, EM Rathje, KW Campbell, WJ Silva, B Xu, M Musgrove, O Ilhan (201x). Site amplification functions for central and eastern North America - Part I: Simulation dataset development, *Earthquake Spectra*. In revision.

Harmon, G, YMA Hashash, JP Stewart, EM Rathje, KW Campbell, WJ Silva, O Ilhan (201x). Site amplification functions for central and eastern North America - Part II: Modular simulation-based models, *Earthquake Spectra*. In revision

Parker, GA, JP Stewart, YMA Hashash, EM Rathje, KW Campbell, and WJ Silva (201x). Empirical linear seismic site amplification in central and eastern North America, *Earthquake Spectra*. In revision

Stewart, JP, GA Parker, JP Harmon, GM Atkinson, DM Boore, RB Darragh, WJ Silva, and YMA Hashash (2017). Expert panel recommendations for ergodic site amplification in central and eastern North America, *PEER Report 2017/04*, Pacific Earthquake Engineering Research Center, Berkeley, CA.

Hashash, YMA, JA Harmon, O Ilhan, GA Parker, and JP Stewart, 2017. Recommendations for Ergodic Nonlinear Site Amplification in Central and Eastern North America, *PEER Report 2017/05*, Pacific Earthquake Engineering Research Center, Berkeley, CA.

Outline

1. Geotechnical Working Group scope
2. Expert panel: objectives & scope
3. Panel findings and recommendations
4. Responses to USGS questions

GWG Scope

- Reference site condition: V_S and κ_0
- Site conditions at CENA ground motion stations: profiles and proxies
- Studies to support large-scale ground response simulations: EL vs NL analysis, incorporating shear strength
- Ground response simulations and model development
- Empirical linear site amplification model development

GWG Scope

- Reference site condition: V_S and κ_0
- Site conditions at CENA ground motion stations: profiles and proxies
- Studies to support large-scale ground response simulations: EL vs NL analysis, incorporating shear strength
- **Ground response simulations and model development**
- Empirical linear site amplification model development

Simulation-Based Model

Modular

$$F = F_{lin} + F_{nl}$$

Simulation-Based Model

Modular

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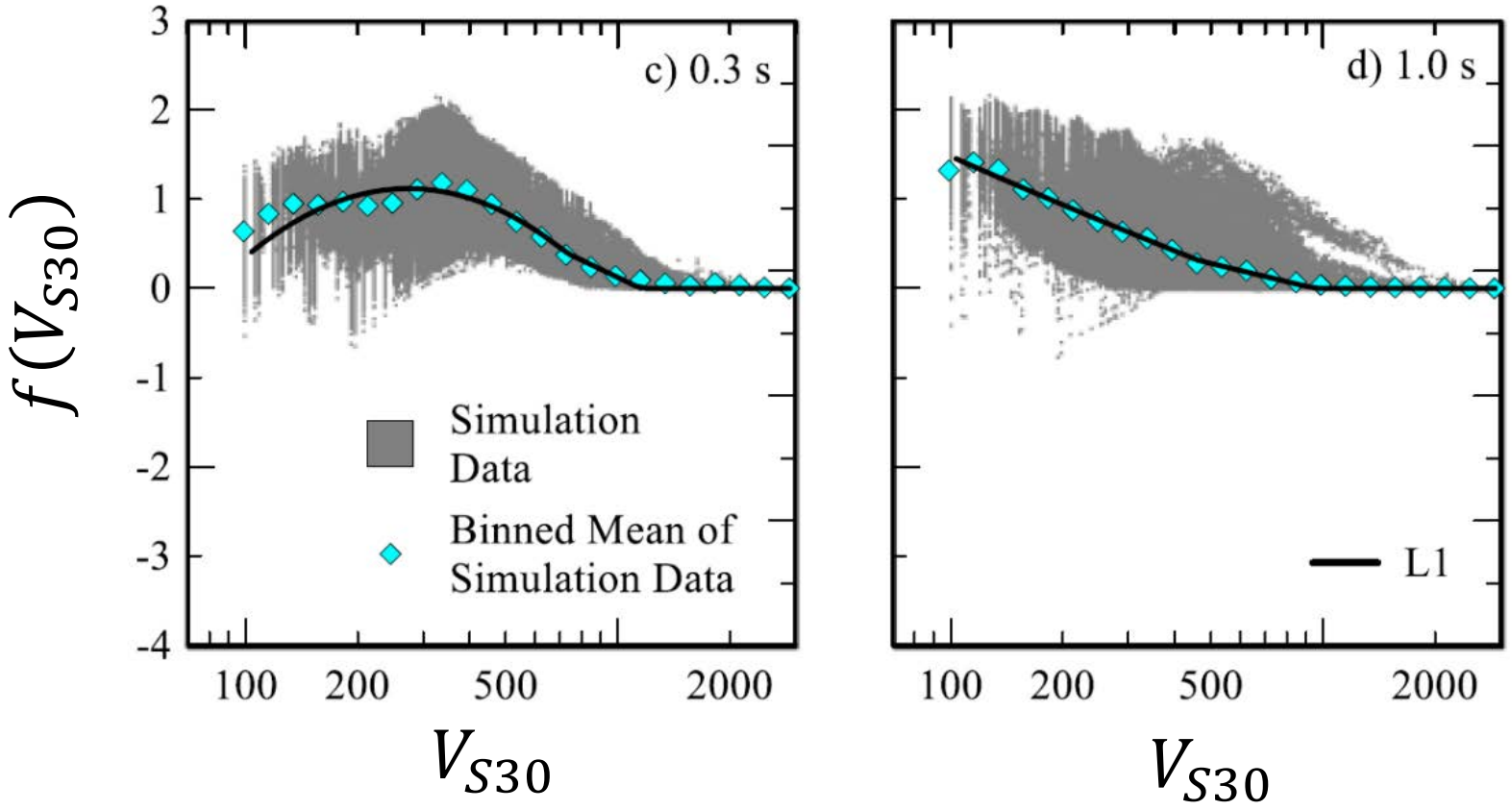
Simulation-Based Model

Modular

$$F = \boldsymbol{F_{lin}} + F_{nl}$$

$$F_{lin} = f(V_{S30})$$



Harmon et al. (201x)

Simulation-Based Model

Modular

$$F = \boldsymbol{F_{lin}} + F_{nl}$$

$$F_{lin} = f(V_{S30}) + \begin{cases} f(T_{nat}) \\ f(Z_{soil}) \end{cases}$$

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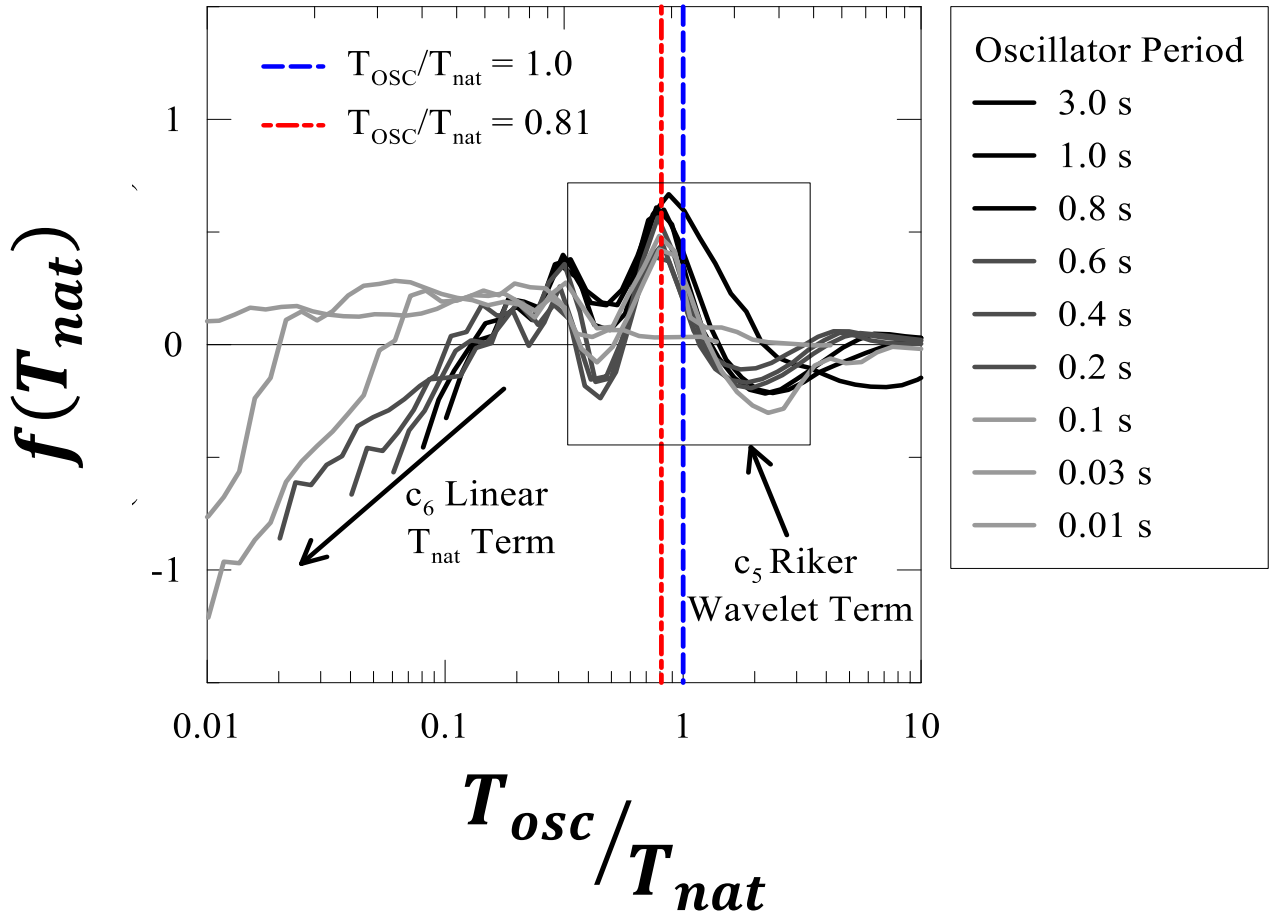

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Modular

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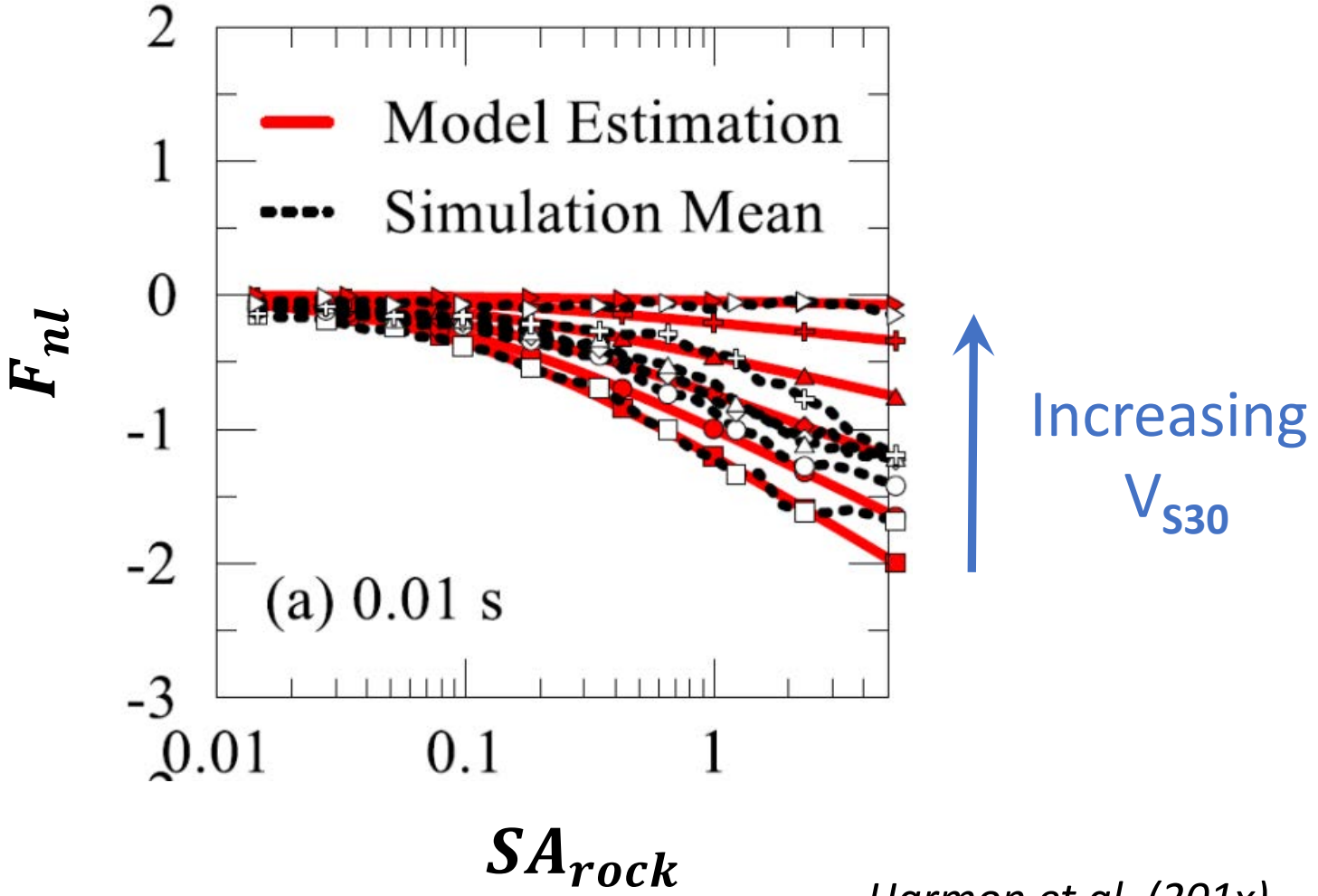

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GWG Scope

- Reference site condition: V_S and κ_0
- Site conditions at CENA ground motion stations: profiles and proxies
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Empirical Model

Non-reference site approach

Independent estimate of F_{lin} term

Normalized to V_{S30} = 760 m/s, denoted F_V

Amplification relative to 3000 m/s requires additional term, F_{760}.

Empirical Model

Non-reference site approach

Independent estimate of F_{lin} term

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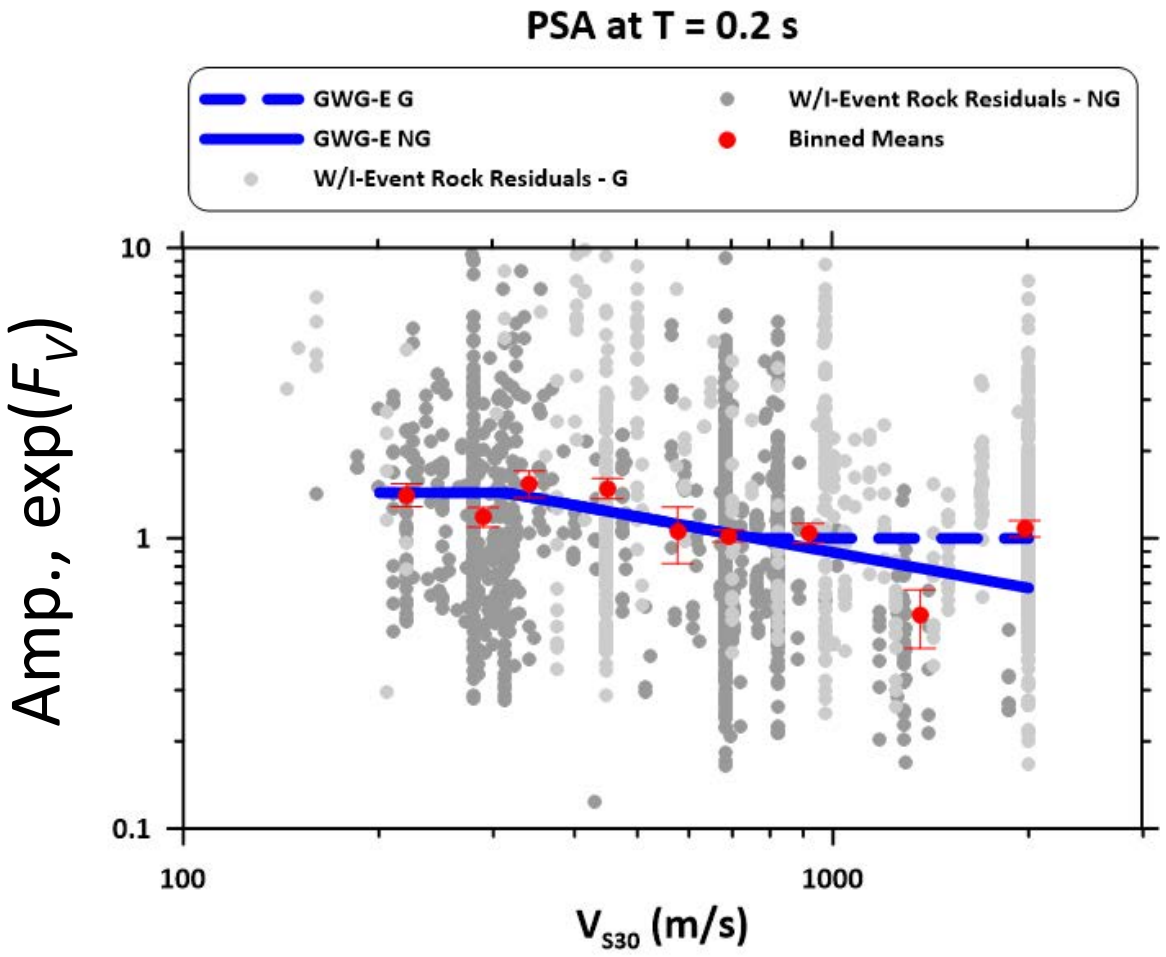
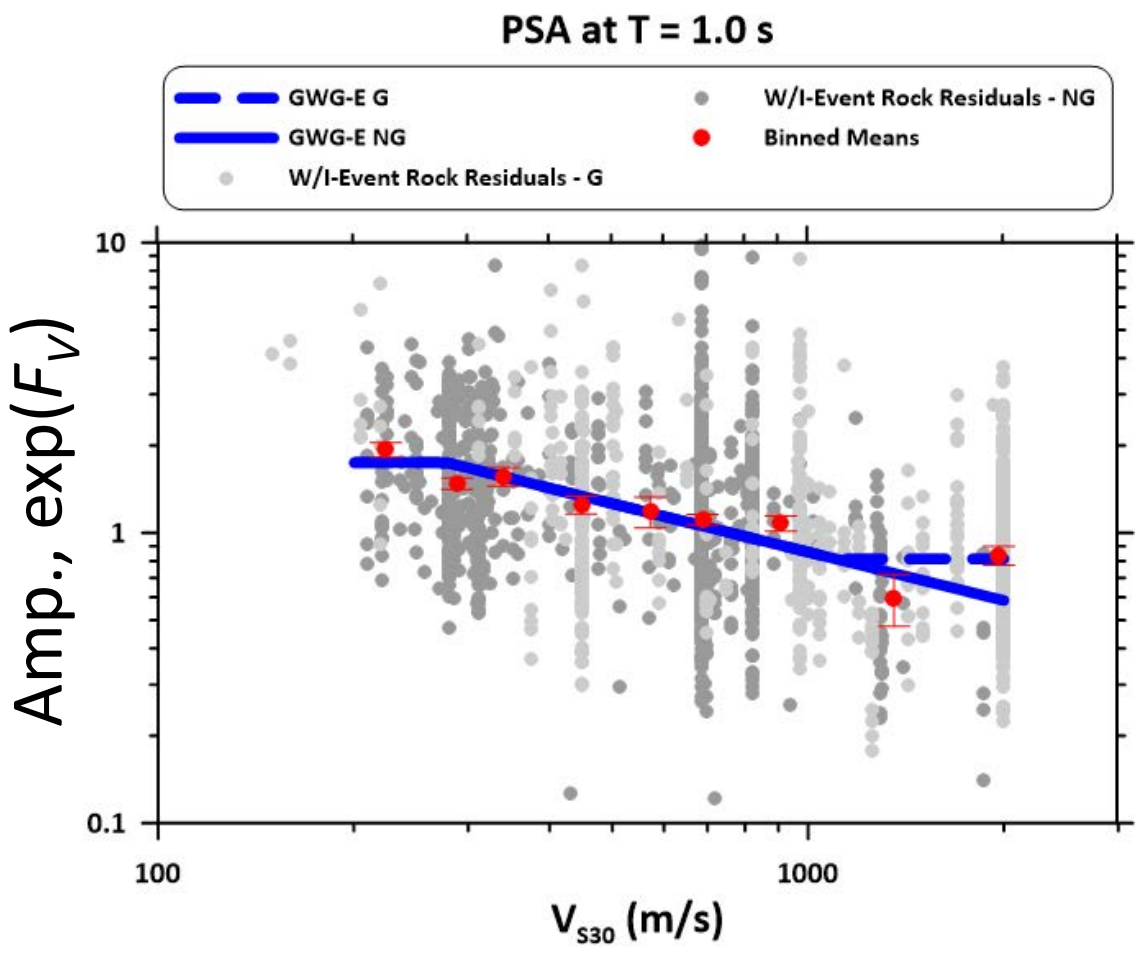
Amplification relative to 3000 m/s requires additional term, F_{760}.

Empirically constrained

Simulation-based

Empirical Model





Parker et al. (201x)

Outline

1. Geotechnical Working Group scope
2. **Expert panel: objectives & scope**
3. Panel findings and recommendations
4. Responses to USGS questions

Panel Objectives

NGA-East GMMs apply for 3 km/s reference condition

Applications require site factors for slower V_{S30}

To be used directly in hazard calculations, not as tabulated factors (Project 17)

Provide recommendations to USGS to support V_{S30} -based hazard analysis using ergodic models

Recommendations not provided for site-specific analysis in CENA

Panel Scope

Review available models

- Pre-NGA-East
- Concurrent with NGA-East but not by GWG
- GWG models

Provide recommended models for:

- V_{S30}-scaling, F_V
- 760 to 3000 m/s adjustment, F_{760}
- Nonlinear effects

Characterize, or estimate, uncertainties

Outline

1. Geotechnical Working Group scope
2. Expert panel: objectives & scope
3. **Panel findings and recommendations**
4. Responses to USGS questions

Scope

Model review

Recommended models

Uncertainties

Model Review

Prior applications – mostly NGA-W2 models.

Simulation-based models for Mississippi embayment

- Hashash and Park 2001; Romero and Rix 2001; Park and Hashash 2005; Hashash et al. 2008

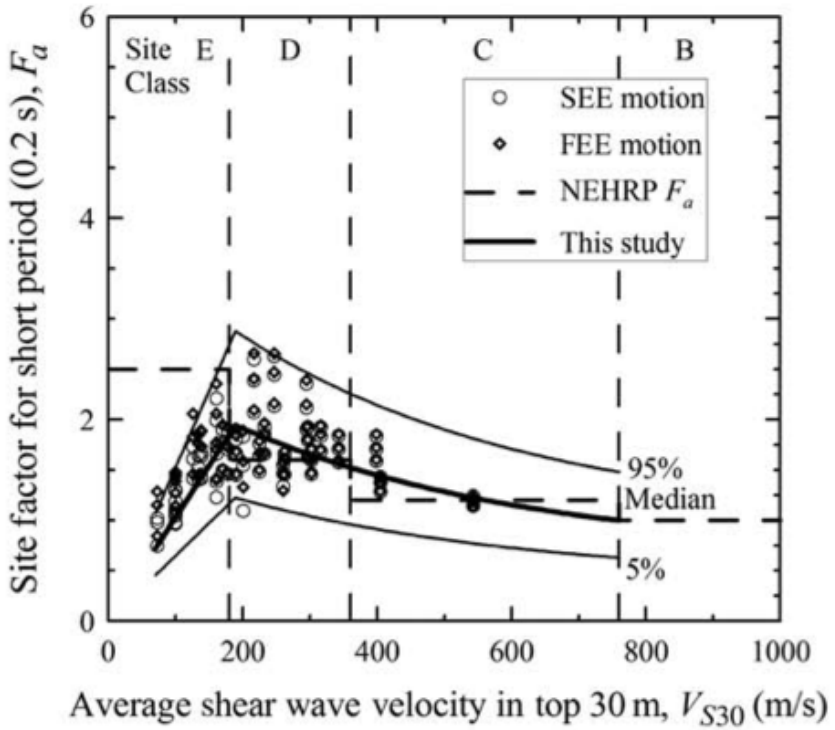
Simulation-based models for NEHRP site categories

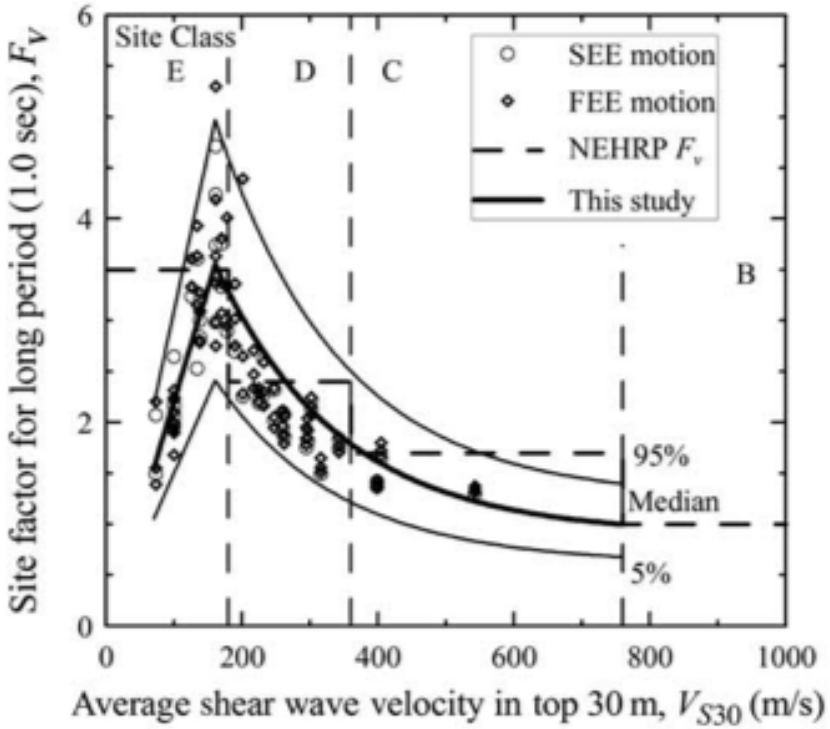
- Hwang et al. (1997)

Model Review

Coincident with NGA-East/GWG

Charleston, South Carolina model: Aboye et al. (2014)

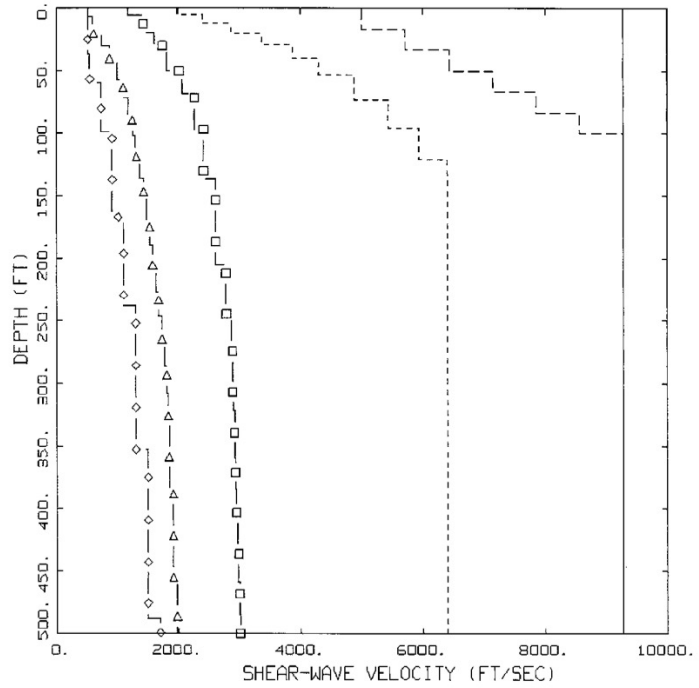




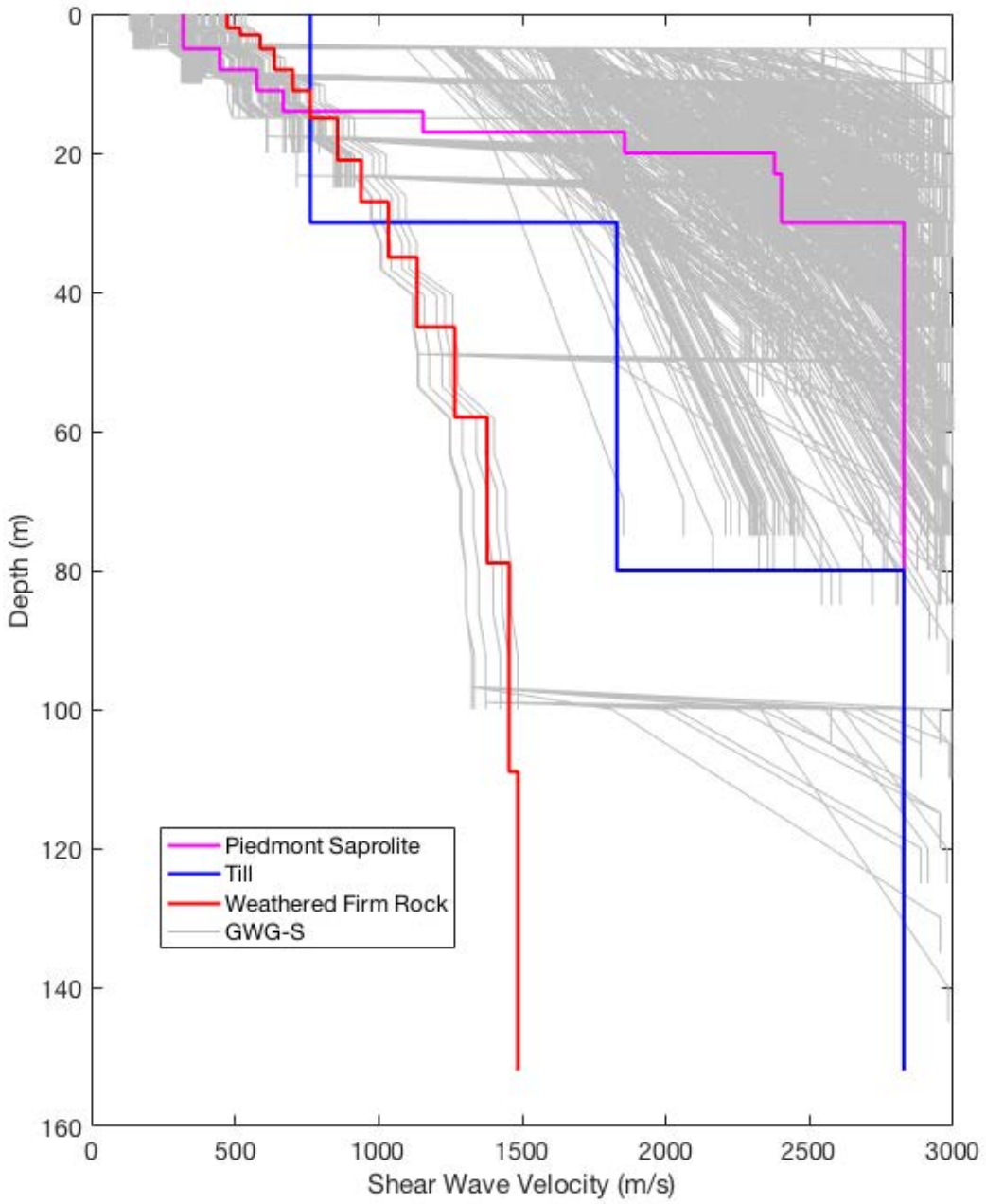
Model Review

Coincident with NGA-East/GWG

Simulations for NEHRP classes. Darragh et al. (2015)



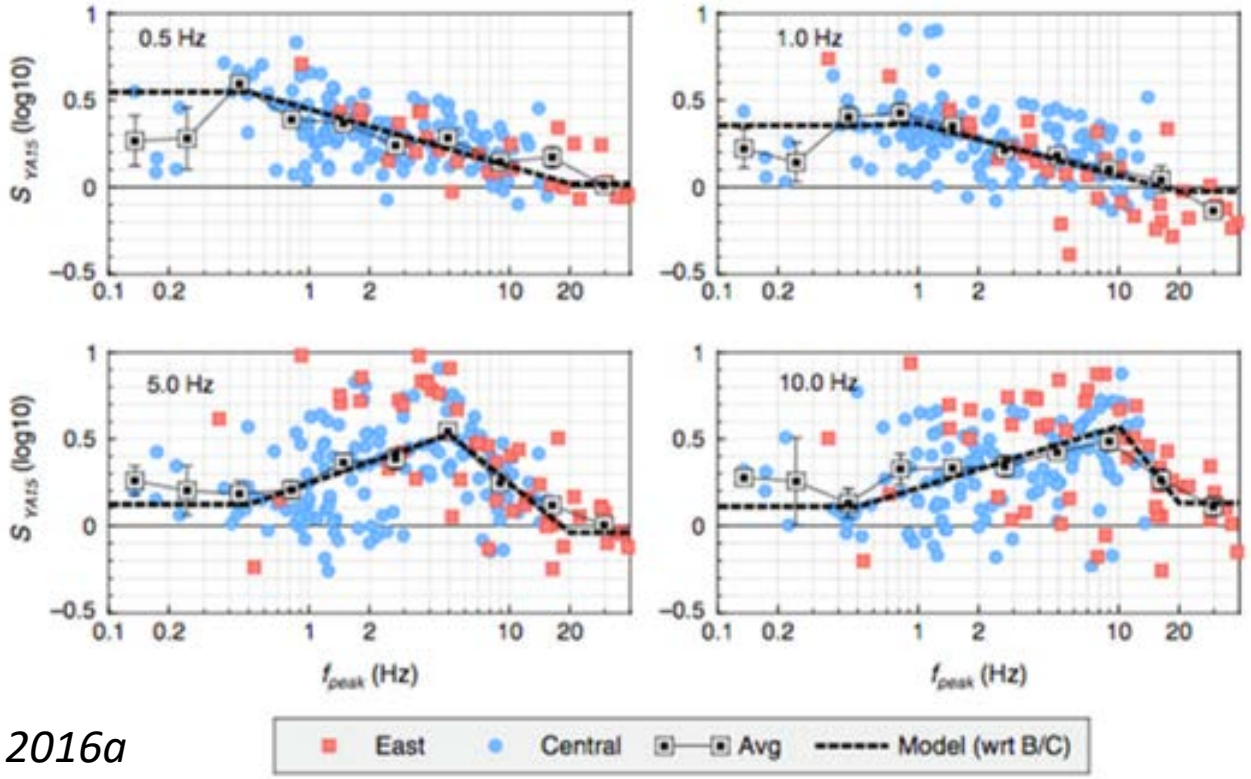
CENA SHEAR WAVE PROFILES



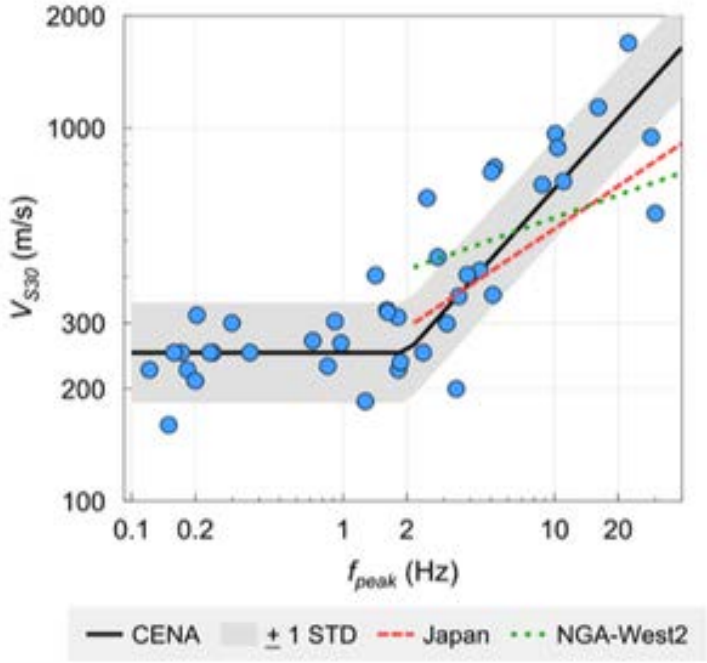
Model Review

Coincident with NGA-East/GWG

Empirical, conditioned on f_{peak} from H/V spectral ratios, Hassani and Atkinson (2016a,b)



HA 2016a



HA 2016b

Recommended Model

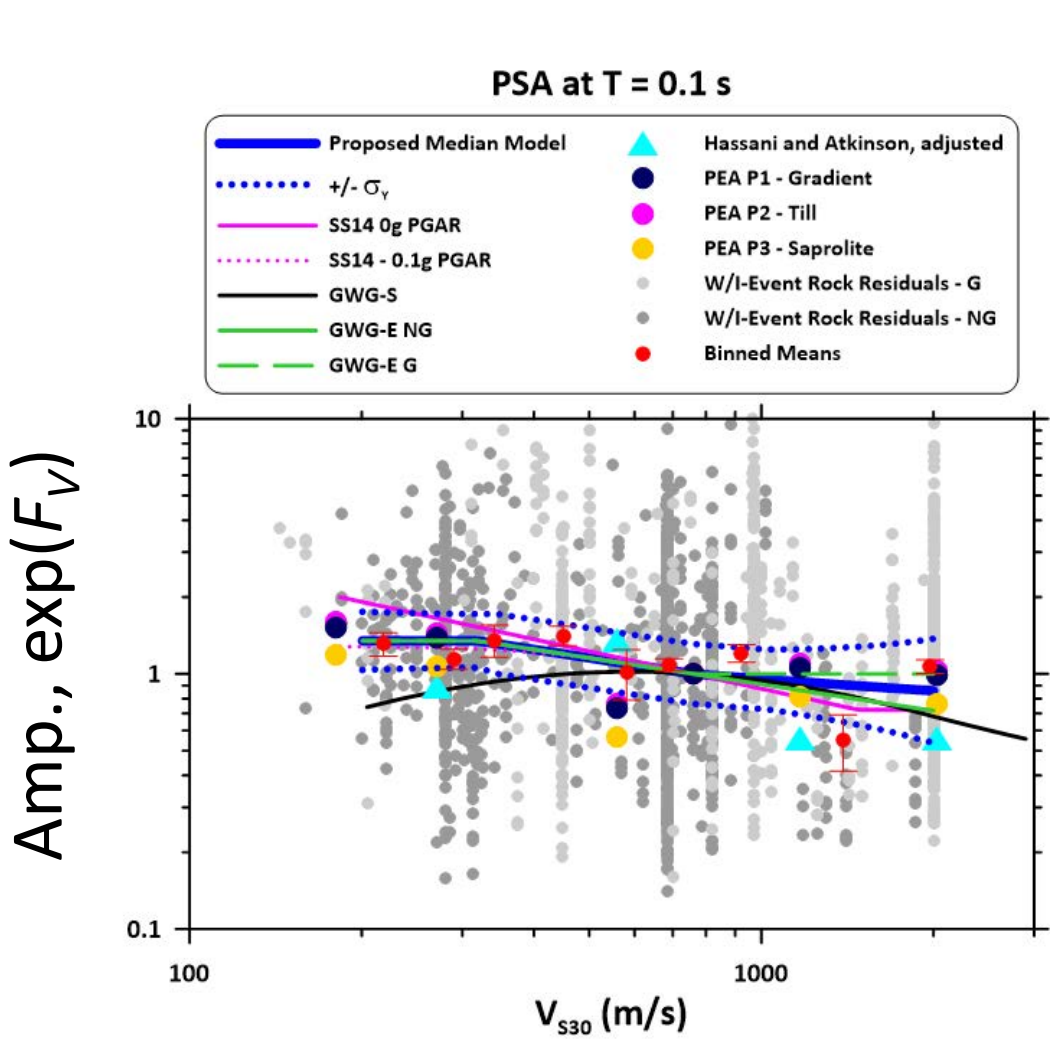
$$F = F_V + F_{760} + F_{nl}$$

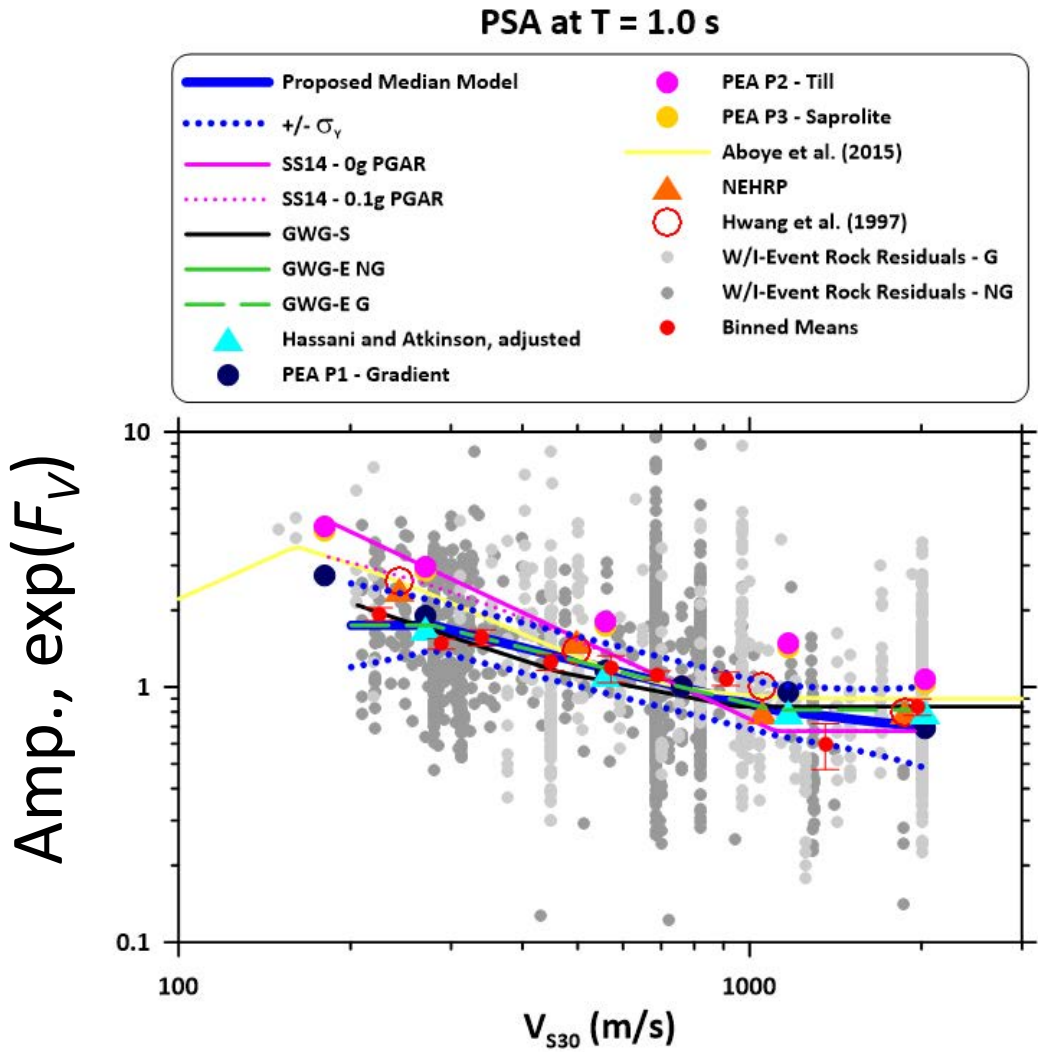
F_V: linear amplification relative to 760 m/s

F_{760}: linear amplification, 760 m/s relative to 3000 m/s

F_{nl}: nonlinear amplification, depends on V_{S30}

F_V model


PSA at T = 0.1 s
Proposed Median Model
+/- σγ
SS14 0g PGAR
SS14 - 0.1g PGAR
GWG-S
GWG-E NG
GWG-E G
Hassani and Atkinson, adjusted
PEA P1 - Gradient
PEA P2 - Till
PEA P3 - Saprolite
W/I-Event Rock Residuals - G
W/I-Event Rock Residuals - NG
Binned Means
Amp., exp(FV)
10
1
0.1
100
1000
VS30 (m/s)


PSA at T = 1.0 s
Proposed Median Model
+/- σγ
SS14 - 0g PGAR
SS14 - 0.1g PGAR
GWG-S
GWG-E NG
GWG-E G
Hassani and Atkinson, adjusted
PEA P1 - Gradient
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Aboye et al. (2015)
NEHRP
Hwang et al. (1997)
W/I-Event Rock Residuals - G
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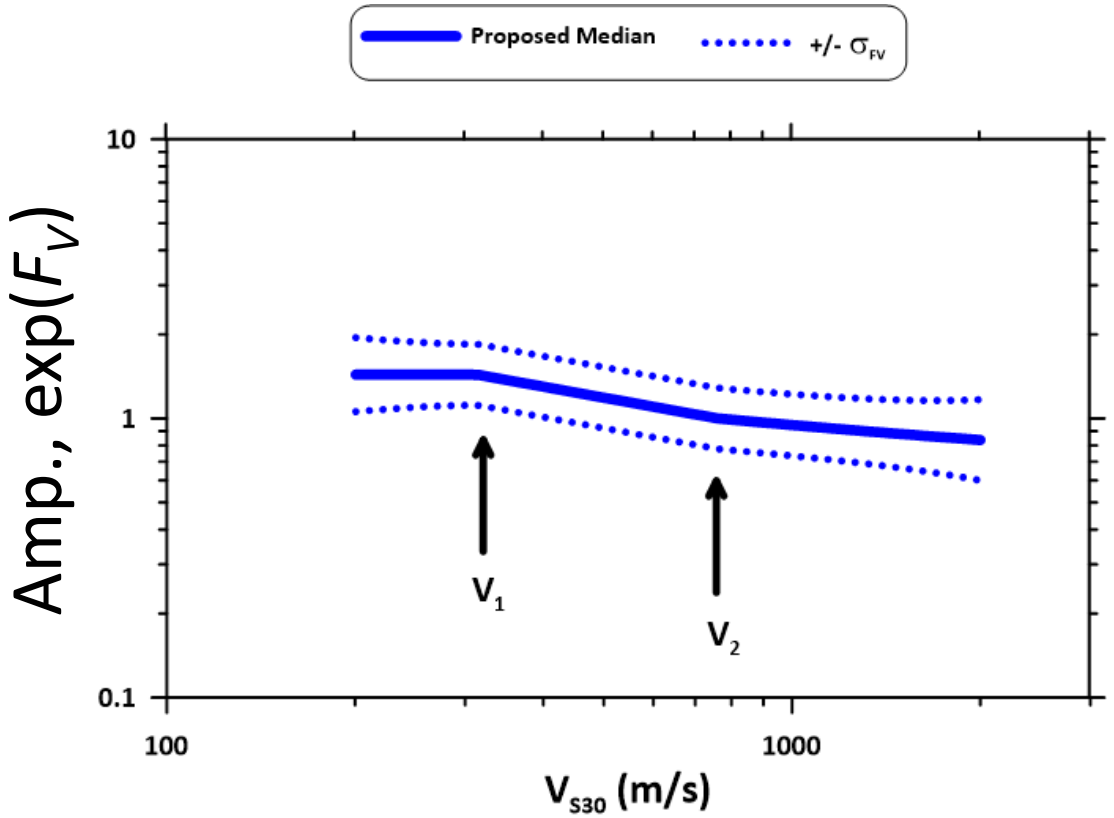
Binned Means
Amp., exp(FV)
10
1
0.1
100
1000
VS30 (m/s)

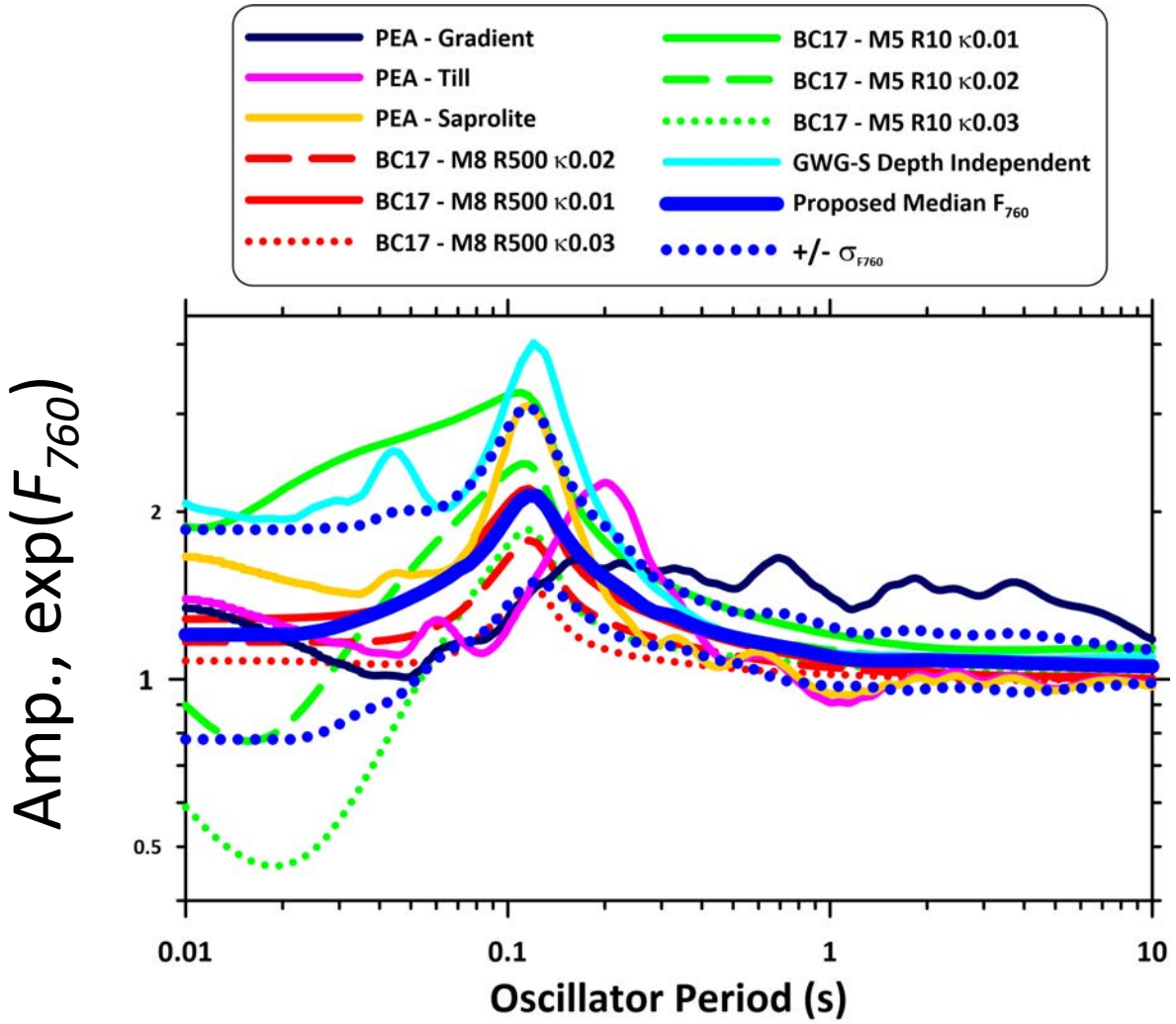
F_V model



$$F_V = \begin{cases} c\ln\left(\frac{V_1}{V_{ref}}\right) for\ V_{S30} \leq V_1 \\ c\ln\left(\frac{V_{S30}}{V_{ref}}\right) for\ V_1 < V_{S30} \leq V_2 \\ c\ln\left(\frac{V_2}{V_{ref}}\right) + \frac{c}{2}ln\left(\frac{V_{S30}}{V_2}\right) for\ V_{S30} > V_2 \end{cases}$$

Uncertainty flares at limits of range

F_{760} model

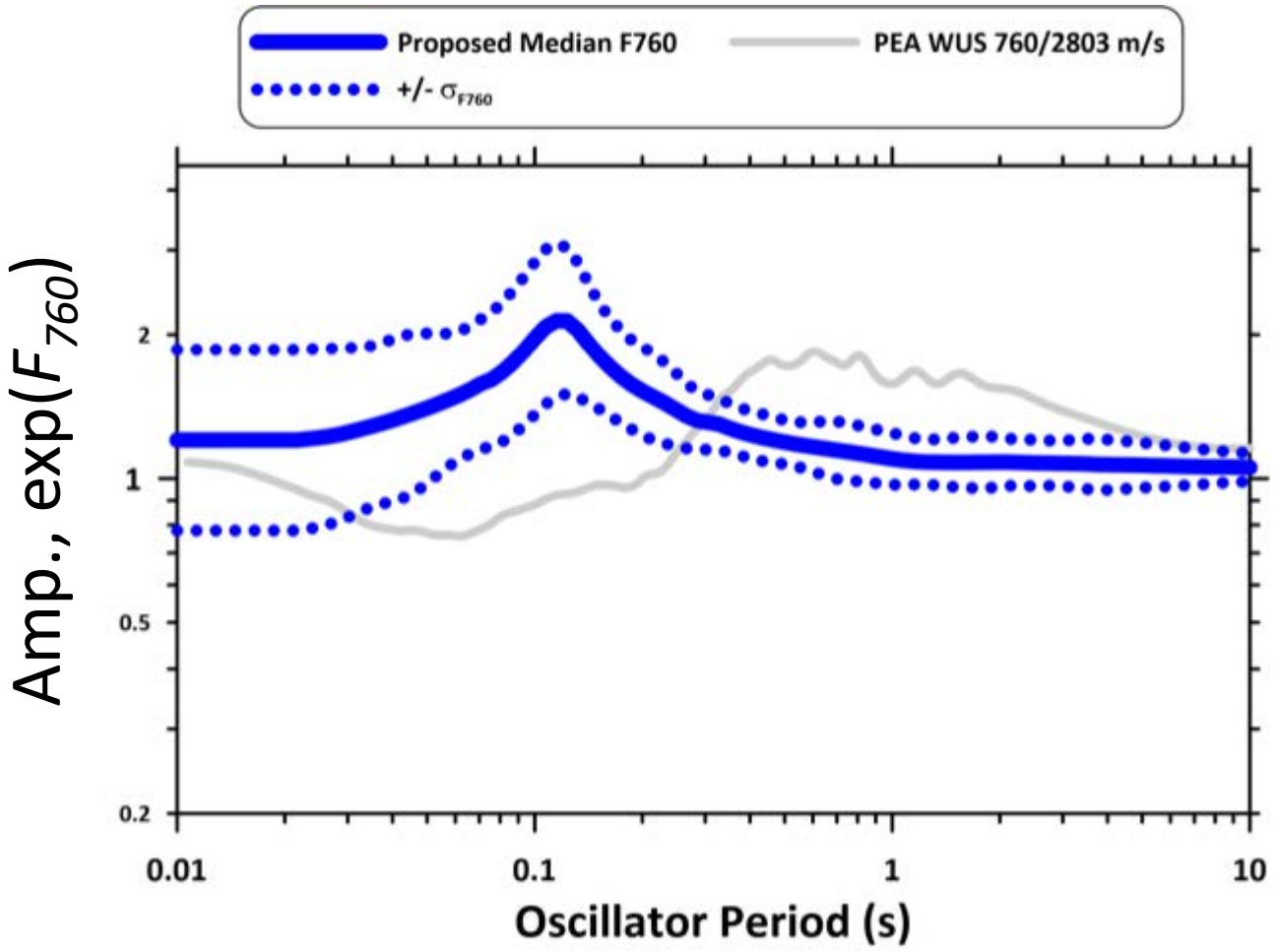


Considered models from:

1. Boore and Campbell (2017)
2. Darragh et al. (2015)
3. Hashash et al. (2017)

Used geo mean with some smoothing

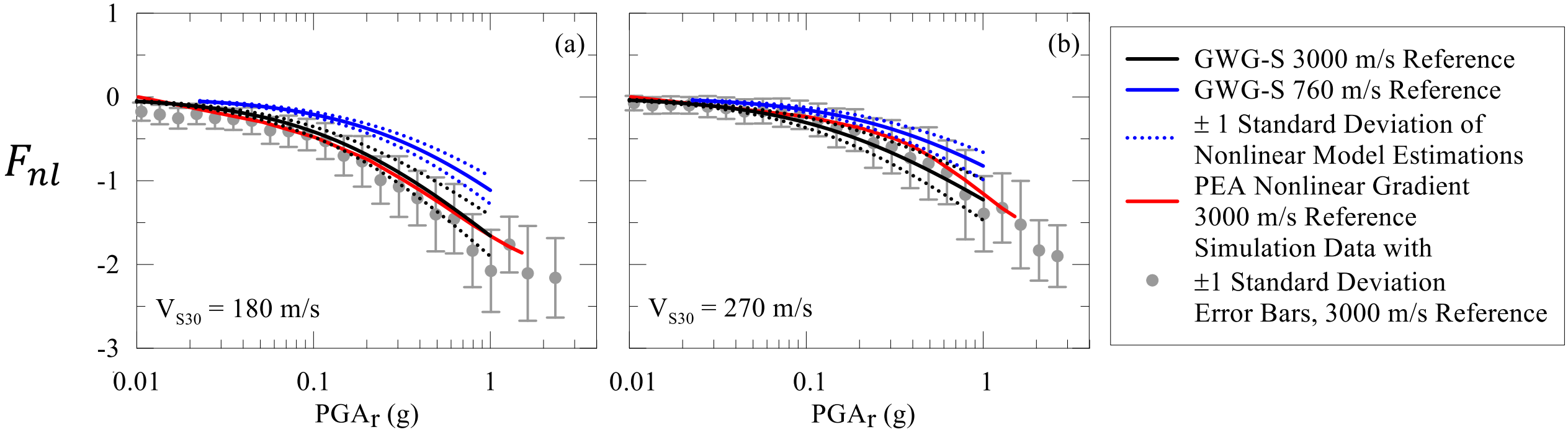
F_{760} model: Comparison to WUS



Courtesy Walt Silva and Bob Darragh, PEA

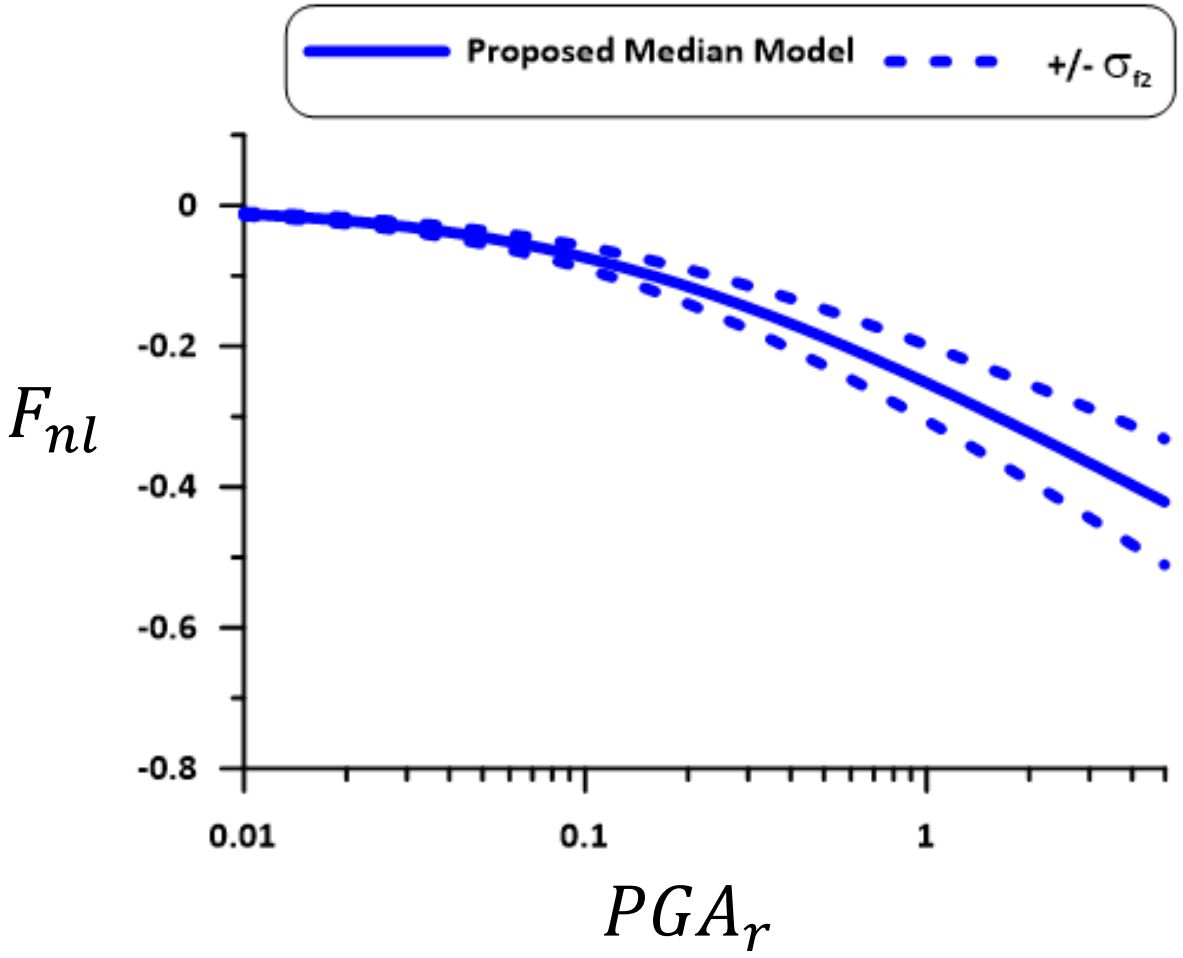
F_{nl} model

Results considered: Darragh et al. (2015), Harmon et al. (201x)



F_{nl} model

Recommended model



$$F_{nl} = \begin{cases} f_2 ln\left(\frac{PGA_r + f_3}{f_3}\right) for\ V_{S30} < V_c \\ 0\ for\ V_{S30} \geq V_c \end{cases}$$

$$f_2 = f_4 \left[\begin{matrix} exp\{f_5[min(V_{S30}, V_{ref}) - 360]\} \\ -exp\{f_5(V_{ref} - 360)\} \end{matrix} \right]$$

Uncertainty is on f_2

Outline

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Why should the USGS use the new CENA amplification factors?

Because the proposed factors were developed specifically for the geological conditions present in CENA.

They better reflect site amplification trends and its uncertainty than current models

Are they better than the current NEHRP factors? How do they compare?

Yes, current factors are now understood to be biased for application in CENA

Weaker V_{S30}-scaling in CENA

Different F_{760}

Larger uncertainty

Why are these factors reasonable for use in the 2018 NSHM?

Procedures used in their development mirror those applied in active regions

Models have been subject to rigorous peer/panel review

Recommended models are published

What are the limitations to this model (periods, site classes, basin terms)?

They do not capture effects of resonant peaks, which are significant for CENA sites with large impedance contrasts.

Poorly constrained for V_{S30} < 200 m/s, PGA, and T > 5 sec

We lack empirical basin terms due to lack of available basin models at the time the models were developed.

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