PACIFIC EARTHQUAKE ENGINEERING
RESEARCH CENTER

Recommendation for Ergodic Nonlinear Site Amplification in Central and Eastern North America

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ABSTRACT

This document is a companion report to Expert Panel Recommendation for Ergodic Linear Site Amplification Models in central and eastern North America (*PEER Report 2017/04*, Stewart et al. 2017). This report describes the panel recommendations for ergodic median nonlinear site amplification models, which are meant to accompany linear models in the companion report. Nonlinear models for site amplification must represent the strength of the input ground motion in some manner, and peak acceleration for a reference condition (PGA_r) is often used. The use of PGA_r (and similar parameters) requires specification of a reference condition in the development of nonlinear models, and those provided here consider reference conditions of V_S = 3000 m/sec and V_{S30} = 760 m/sec. One of the proposed models (the GWG-S nonlinear amplification model) is derived for a reference condition of V_S = 3000 m/sec. A second is identical to the first except that PGA_r is adjusted to a V_{S30} = 760 m/sec reference condition.

Nonlinear amplification models in this report are produced as functions of V_{S30} and (PGA_r). Other models evaluated in this report are the PEA nonlinear amplification model and the GWG-S model with an alternative approach to convert GWG-S nonlinear amplification model estimations to a V_{S30} = 760 m/sec reference condition. A recommended epistemic uncertainty model on the GWG-S recommended median nonlinear amplification models is provided in piecewise functional form to generate reasonable variation of F_{nl} across the period and V_{S30} ranges of interest. Limitations on the recommended models are presented considering both the methodology of the recommended model derivation and limitations of nonlinear amplification models in general.

ACKNOWLEDGMENTS

This project was sponsored by U.S. Geological Survey (USGS) contract G16AP00005. We thank Mark Petersen of USGS for consulting with the panel over the course of the work and providing valuable input. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect those of the USGS.

CONTENTS

LIST OF TABLES AND FIGURES

1 INTRODUCTION

1.1 MOTIVATION FOR PROJECT AND RELATIONSHIP TO LINEAR MODEL

The Next Generation Attenuation East (NGA-East) Project is multi-disciplinary research project coordinated by Pacific Earthquake Engineering Research Center (PEER) that generated a list of ground motion models (GMM's) for central and eastern North America (CENA). Current GMM's development for CENA during the NGA-East project are given namely, Boore [2015b], Darragh et al. [2015], Yenier and Atkinson [2015], Pezeshk et al. [2015], Frankel [2015], Shahjouei and Pezeshk [2015], Al Noman and Cramer [2015], Graizer [2015], Hassani and Atkinson [2015], and Hollenback et al. [2015]. Because of the lack of strong ground-motion recordings in CENA, nonlinear site effects included in the site terms have no effect on model development.

A previous generation of GMM's was reviewed by an international team of experts as a part of the global earthquake model project [Stewart et al. 2015]. Many of these models are used in the current versions of the USGS national hazard maps [Petersen et al. 2015] in the CENA region, namely Frankel et al. [1996], Toro et al. [1997],Somerville et al. [2001], Silva et al. [2002a], Campbell [2003], Tavakoli and Pezeshk [2005], Atkinson and Boore [2006] and Pezeshk et al. [2011]. In general, these models either lack model terms for nonlinear site effects or site effects in these GMM's are not applicable for use in CENA [Stewart et al. 2015].

Both generations of aforementioned models have been developed for a hard-rock reference condition similar to the proposed condition of V_S = 3000 m/sec in Hashash et al. [2014]. However, national ground motion hazard maps have been developed relative to a V_{S30} = 760 m/sec reference condition [Frankel et al. 1996; Petersen et al. 2008; and Petersen et al. 2014] and) where V_{S30} is the time average shear wave velocity in the top 30 m of a site. This reference-rock condition incompatibility between GMM's and hazard maps reveals the longstanding need of correction of hard rock GMM's to a 760 m/sec condition. This document is a companion report to Expert Panel Recommendations for Ergodic Site Amplification in Central and Eastern North America [Stewart et al. 2017] developed for linear site amplification assessment, and presents recommendations for the nonlinear component of site amplification models for reference conditions of both 760 m/sec and 3000 m/sec. The nonlinear amplification models use a common functional form and include a conversion from 760 m/sec to 3000 m/sec to modify reference rock peak ground acceleration (PGA) values to the appropriate reference condition. An uncertainty model derived from judgment and the functional form of the proposed median amplification models is included.

It should be noted that this report refers to several linear and nonlinear models from the Geotechnical Working Group (GWG) of NGA-East that are currently being finalized [Harmon 2017; Parker et al. 2017].

1.2 ORGANIZATION OF THE REPORT

In this report, Section 2 presents recommended median nonlinear amplification models and the associated uncertainty for V_{S30} = 760 m/sec and V_S = 3000 m/sec reference conditions. Section 3 presents the nonlinear amplification models and methodology used to determine the recommended median models and associated uncertainty. The nonlinear amplification models considered are (1) the Harmon et al [2017] nonlinear amplification model relative to a V_S = 3000 m/sec reference-rock condition (referred to as the GWG-S model), (2) the Darragh et al. [2015] nonlinear amplification model (referred to as the Pacific Engineering & Analysis (PEA) model), and (3) the GWG-S model converted to a V_{S30} = 760 m/sec reference condition. The epistemic uncertainty model is derived from visual inspection of the nonlinear amplification models and physical considerations. Section 4 of this report gives a summary of the recommended nonlinear models and their limitations, and the conclusions of the report are given in Section 5.

2 RECOMMENDED NONLINEAR AMPLIFICATION MODEL

2.1 APPROACH

The response spectrum amplification, (F_S), is commonly represented as the sum of an intensity independent linear amplification component (F_{lin}) and a nonlinear site amplification (F_{nl}) component as given in Equation (2.1) as

$$F_S = F_{lin} + F_{nl} \tag{2.1}$$

The following sections present recommended median nonlinear amplification models for F_{lin} Two median models with estimated epistemic uncertainty are recommended for the reference conditions of 760 m/sec and 3000 m/sec. The model relative to 3000 m/sec is the N2 GWG-S amplification model [Harmon 2017], and the nonlinear model relative to a 760 m/sec condition is derived from the GWG-S model relative to 3000 m/sec. The conversion between a 760 m/sec reference condition and the 3000 m/sec condition is performed on the input PGA and is adopted from depth-independent 760/3000 m/sec correction at T = 0.001 sec GWG-S linear amplification simulations in Harmon [2017].

The epistemic uncertainty on the recommended median nonlinear amplification models is derived using judgement, with the objective of producing a reasonable variation of F_{nl} across the period and V_{S30} range of interest and is derived from the functional form of the recommended GWG-S median models.

2.2 RECOMMENDED MODEL FORM AND COEFFICIENTS

The recommended median nonlinear amplification model form is presented in Equations (2.2) and (2.3) as a function of site V_{S30} and PGA from a reference condition of V_S = 3000 m/sec $\left(I_{r,3000}\right)$. The model form in Equation (2.2) can be modified with the reference-rock conversion in Equation (2.4) to produce the recommended median nonlinear amplification model for site V_{S30} and PGA from a reference-rock condition of V_{S30} = 760 m/sec.

$$F_{nl} = \begin{cases} f_2 \ln\left(I_{r,3000} + f_3 / f_3\right) & V_{S30} < V \\ 0 & V_{S30} \geq V \end{cases} \tag{2.2}$$

where F_{nl} is the nonlinear site amplification, V_c is a period dependent limiting site V_{S30} for nonlinearity, f_3 is a model coefficient, and f_2 is defined in Equation (2.3) as

$$f_2 = f_4 \left[\exp\left\{ f_5 \left[\min\left(V_{S30}, V_{\text{ref}}\right) - 360 \right] \right\} - \exp\left\{ f_5 \left(V_{\text{ref}} - 360\right) \right\} \right] \tag{2.3}$$

where f_4 and f_5 are model coefficients, and V_{ref} is the reference-rock condition of 3000 m/sec. The coefficients f_3, f_4, f_5, and V_c are identically the GWG-S nonlinear coefficients derived in Harmon [2017] and reproduced in Table 2.1 for periods of 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8, 1.0, 2.0, 3.0, 4.0, 5.0, and 10.0 sec, and shown in Figure 2.1. The parameter $I_{r,3000}$ in Equation (2.2) can be calculated from Equation (2.4) for PGA values computed from a reference condition of 760 m/sec as

$$I_{r,3000} = I_{r.760} / C_{760/3000} = I_{r,360} / 2.275 \tag{2.4}$$

where $I_{r.760}$ is the rock outcrop PGA relative to 760 m/sec, and $C_{760/3000}$ is a conversion factor between a 760 m/sec and 3000 m/sec reference condition. $C_{760/3000}$ represents the depth-independent 760–3000 m/sec correction factor from the GWG-S linear amplification model presented in Harmon [2017] at 0.001 sec and is equal to 2.275.

Epistemic uncertainty on the recommended nonlinear amplification models (i.e., the median recommended amplification models for PGA relative to V_S conditions of 3000 m/sec and 760 m/sec) is obtained by functional form in the Equation (2.5) as

$$\sigma_{f2} = \begin{cases} \sigma_c & V_{S30} < 300 \text{ m/sec} \\ \left[\dfrac{-\sigma_c}{\ln\left(\dfrac{1000}{300}\right)} \right] * \ln\left(\dfrac{V_{S30}}{300}\right) + \sigma_c & 300 \le V_{S30} < 1000 \text{ m/sec} \\ 0 & V_{S30} \ge 1000 \text{ m/sec} \end{cases} \tag{2.5}$$

where σ_c is given in Table 2.1 for periods of 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8, 1.0, 2.0, 3.0, 4.0, 5.0, and 10.0 sec and shown in Figure 2.2.

Table 2.1 Recommended nonlinear amplification model and uncertainty model coefficients.

Period (Sec)	f_3	f_4	f_5	V_c m/sec	σ_c	$C_{760/3000}$
0.08	0.16249	-0.50667	-0.00273	2990	0.12	2.275
0.1	0.15083	-0.44661	-0.00335	2990	0.12	2.275
0.2	0.12815	-0.30481	-0.00488	1533	0.12	2.275
0.3	0.1307	-0.22825	-0.00655	1152	0.15	2.275
0.4	0.09414	-0.11591	-0.00872	1018	0.15	2.275
0.5	0.09888	-0.07793	-0.01028	938	0.15	2.275
0.8	0.07357	-0.01592	-0.01515	832	0.1	2.275
1	0.04367	-0.00478	-0.01823	951	0.06	2.275
2	0.00164	-0.00236	-0.01296	879	0.04	2.275
3	0.00746	-0.00626	-0.01043	894	0.04	2.275
4	0.00269	-0.00331	-0.01215	875	0.03	2.275
5	0.00242	-0.00256	-0.01325	856	0.02	2.275
10	0.05329	-0.00631	-0.01403	837	0.02	2.275

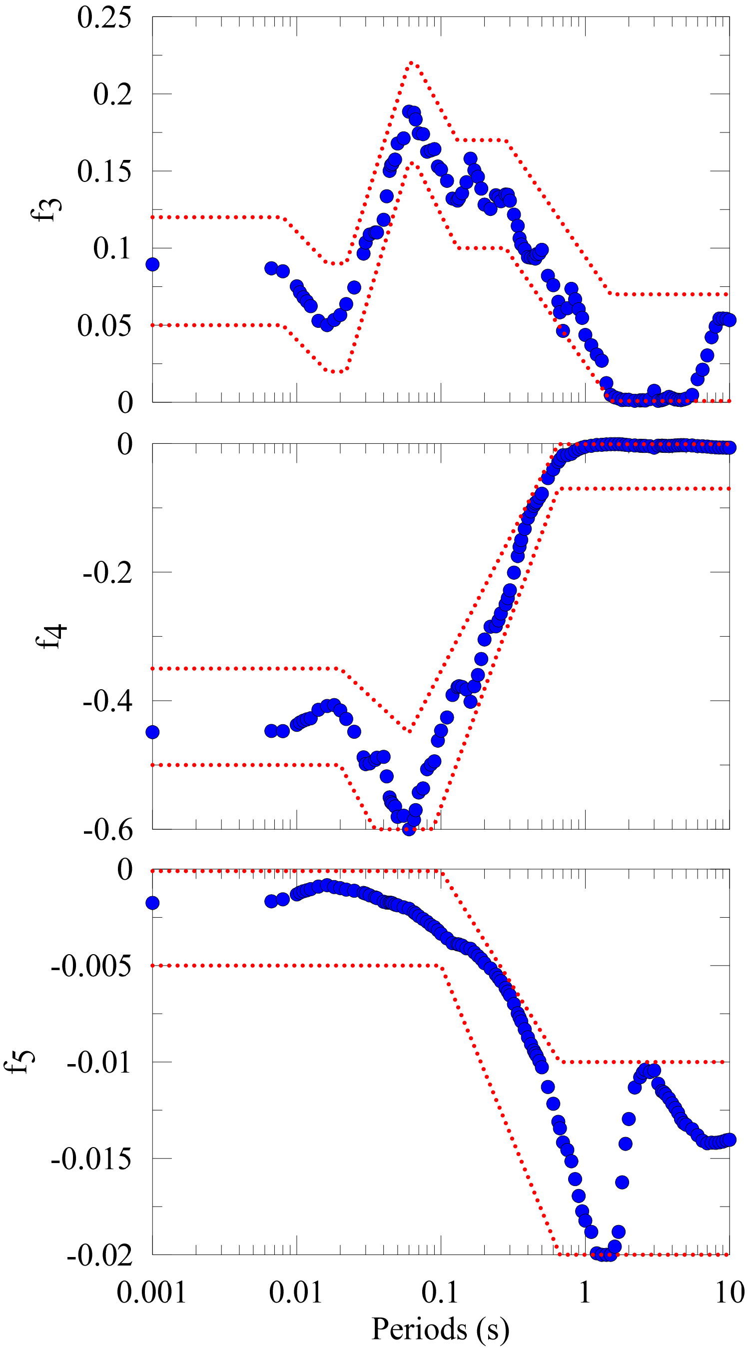

Figure 2.1 **Coefficients of response spectrum nonlinear amplification recommended model relative to 760 m/sec. Dotted red lines indicate bounds used in coefficient regression in Harmon [2017]. Figure modified from Harmon [2017].**

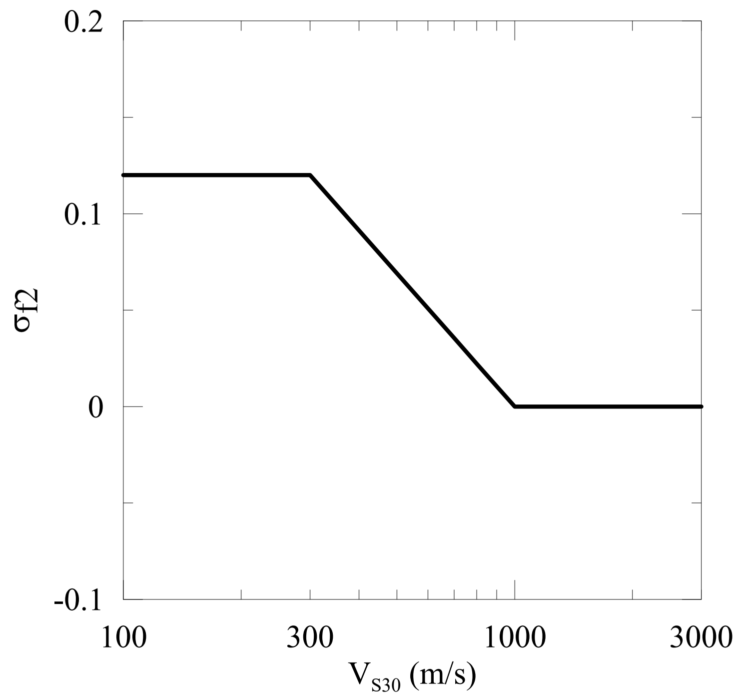

Figure 2.2 **Epistemic uncertainty with respect to V_{S30} at oscillator period value of 0.1 sec.**

3 NONLINEAR AMPLIFICATION MODELS

3.1 INTRODUCTION AND LITERATURE REVIEW

Central and eastern North America (CENA) is considered a stable continental region (SCR) from the perspective of ground motion model development. The lack of strong ground-motion recordings in SCR leads to ground motion models (GMMs) developed from sparse datasets with relatively weak motions or GMMs developed as modifications of GMMs for active seismic regions. For relatively weak ground motions at a site, the soil experiences low levels of strain, and the response of the site is very near the linear site amplification. Site response simulations considering much larger ranges of site conditions and ground shaking levels than available in recorded earthquake data have previously been used to evaluate site nonlinear amplification and supplement models developed from the limited empirical datasets of SCRs to produce amplification functions for use with GMMs in regions such as CENA.

Site amplification model forms are generally defined as functions of V_{S30} and a ground-motion intensity measure to capture linear and nonlinear site amplification. The Choi and Stewart [2005] site amplification models propose separate model terms for the linear amplification as a function of V_{S30} scaling and nonlinear amplification as a function of PGA at the reference-rock condition, PGA_r. PGA_r is commonly used as the driver of nonlinearity for these models (i.e., an indicator of the magnitude of nonlinear site amplification).

Simulation-based nonlinear site amplification models have previously been used to constrain nonlinear site effects in empirical models. The simulation-based Walling et al. [2008] used in the Next Generation Attenuation Relationships (NGA-West) project adopts linear V_{S30} scaling model terms and additional model terms to capture nonlinear site amplification effects as a function of both V_{S30} and PGA_r. The consideration of V_{S30} in the nonlinear site amplification model reflects the idea that a site with initially stiffer material (i.e., higher V_{S30}) will be exposed to less strain during shaking, and less nonlinear amplification will be observed. The Kamai et al. [2014] formulation used in the NGA-West 2 project updates the Walling et al. [2008] form with additional simulations to use two alternative formulations, one which uses PGA_r as the driver of nonlinearity and the other which uses $Sa(T)$, where $Sa(T)$ is the spectral acceleration (SA) from the 5% damped response spectrum (RS) at the period (T) of interest. The Seyhan and Stewart [2014] model uses both simulations and empirical observations of site to update the current NEHRP site amplification models [BSSA 2015]. The Seyhan and Stewart [2014] functional form is modified from the nonlinear site amplification model in Chiou and Youngs [2008].

The CENA site database [Goulet et al. 2014] used in the NGA-East GMM development process is mostly dominated by weak ground motions. The treatment of linear site effects in the NGA-East GMM development is described in Stewart et al. [2017] companion to this report.

In this section, two median models with estimated epistemic uncertainty are recommended for the reference conditions of 760 m/sec and 3000 m/sec. Epistemic uncertainty on the recommended models is provided by a functional form obtained from visual inspection of results and physical considerations. Two approaches (one recommended and one alternative) for converting PGA_r in the nonlinear amplification models between a V_S = 3000 m/sec and V_{S30} = 760 m/sec reference conditions are also discussed in the following section.

3.2 RESPONSE SPECTRUM MODELS CONSIDERED IN PANEL RECOMMENDATION FORMULATIONS

3.2.1 GWG-S Nonlinear Amplification Model Relative to 3000 m/sec Reference Condition

In the suite of amplification models for site amplification relative to a V_S = 3000 m/sec reference condition developed in Harmon [2017] as a part of the NGA-East GWG, two models for the nonlinear site amplification were developed from the difference between linear and nonlinear site amplification simulations. The N1 model uses SA, and the N2 model uses PGA_r as the driver of nonlinearity. Both models adopt the same functional form as Seyhan and Stewart [2014] and use different model coefficients. The uncertainty in the correlation between SA and PGA and ease of implementation with the USGS hazard maps causes the N2 model to be selected over the N1 model for evaluation. The N2 model is hereafter referred to as the GWG Simulation-based

(GWG-S) model. The nonlinear site amplification, F_{nl}, functional form used in the GWG-S model is given in Section 2.2.

It should be noted that the definition of V_c in the GWG-S model is a velocity condition where site amplification relative to the reference-rock condition of 3000 m/sec is not observed and comes from the L1 model in Harmon [2017] for linear amplification as a function of V_{S30} (the V_{S30} scaling model). The V_c values in the GWG-S model are nominally high V_{S30} values above which little to no site nonlinearity is observed in mean amplification data and were included in the model for stability.

3.2.2 GWG-S Nonlinear Amplification Model Relative to 760 m/sec Reference Condition

The GWG-S nonlinear amplification models are developed for a reference-rock condition of 3000 m/sec. For use with USGS hazard maps, two methods of converting the GWG- model to a 760 m/sec reference condition were evaluated: (1) converting the reference rock PGA to a 760 m/sec condition, and (2) converting the reference rock PGA to a 760 m/sec condition and adjusting the reference velocity V_{ref} to a 760 m/sec condition. The conversion of a factor between these reference-rock conditions is commonly referred to as a 760/3000 correction.

The first approach uses the identical equational form given in Equation. (2.2) but includes a conversion factor to change an input $\mathrm{PGA_r}$ from a 760 m/sec condition to the model's native 3000 m/sec condition. The $\mathrm{PGA_r}$ conversion between reference conditions uses the following 760/3000 correction factor in Equation (3.1):

$$I_{r,3000} = I_{r.760} / C_{760/3000} \tag{3.1}$$

where $I_{r,3000}$ is the $\mathrm{PGA_r}$ for a 3000 m/sec condition, $I_{r,760}$ is the $\mathrm{PGA_r}$ for a 760 m/sec condition, and $C_{760/3000}$ is a scalar. With this approach, the V_{ref} factor condition in f_2 coefficient is preserved as 3000 m/sec.

The 760–3000 correction ($C_{760/3000}$) used in Equation (3.1) is obtained the depth-independent 760/3000 correction of Harmon [2017] at a RS period of 0.001 sec. The Harmon [2017] 760/3000 model is derived from 29,541 linear elastic site response simulations for sites with V_{S30} between 700 m/sec and 800 m/sec. The response spectral period of 0.001 sec converges with the PGA and it was determined that 760/3000 correction for 0.001 sec was a suitable approximation of the 760/3000 correction for the PGA. The correction term $C_{760/3000}$ is computed in Equation (3.2) as

$$C_{760/3000} = \exp\left\{\ln\left[\text{Amp}\left(V_{S30} = 760 \text{ m/sec}\right)\right] - \ln\left[\text{Amp}\left(V_{S30} = 3000 \text{ m/sec}\right)\right]\right\} = 2.275 \tag{3.2}$$

where $\ln\left[\text{Amp}\left(V_{S30} = 760 \text{ m/sec}\right)\right]$ is the log mean from the amplification sites with V_{S30} between 700 m/sec and 800 m/sec relative to the amplification of sites with V_{S30} = 3000 m/sec (ln amplification = 0, amplification = 1). $C_{760/3000}$ is equal to 0.822 in log units (2.275). The computation of $C_{760/3000}$ is shown in Figure 3.1.

A second approach of converting the GWG-S model to a 760 m/sec reference condition employs the same procedure outlined above in Equations (3.1) and (3.2) to convert the PGA$_r$, but additionally includes changing V_{ref} in the f_2 equation of Equation (2.3) to 760 m/sec as:

$$f_2 = f_4\left[\exp\left\{f_5\left[\min\left(V_{S30}, V_{\text{ref}} = 760\right) - 360\right]\right\} - \exp\left\{f_5\left(V_{\text{ref}} = 760 - 360\right)\right\}\right] \tag{3.3}$$

This approach changes when nonlinearity in the site amplification model is observed, and prevents site nonlinearity from being estimated in sites with V_{S30} greater than 760 m/sec. A comparison of the GWG-S models relative to 3000 m/sec and 760 m/sec (for both approaches) is shown in Figure 3.2 through Figure 3.14.

Of the two models evaluated to convert the GWG-S model to a reference condition of 760 m/sec, the first approach (scaling of PGA$_r$) is preferred to the second (scaling of P PGA$_r$ GA and setting V_{ref} = 760 m/sec). The second approach including setting V_{ref} to 760 m/sec changes the behavior of the amplification model above 760 m/sec, and re-regression of the amplification terms would be required. Additionally, for some spectral periods, nonlinear amplification in the Harmon [2017] simulations can be observed for sites with V_{S30} > 760 m/sec, and the adjustment of V_{ref} to 760 m/sec will prevent this site nonlinearity from being captured.

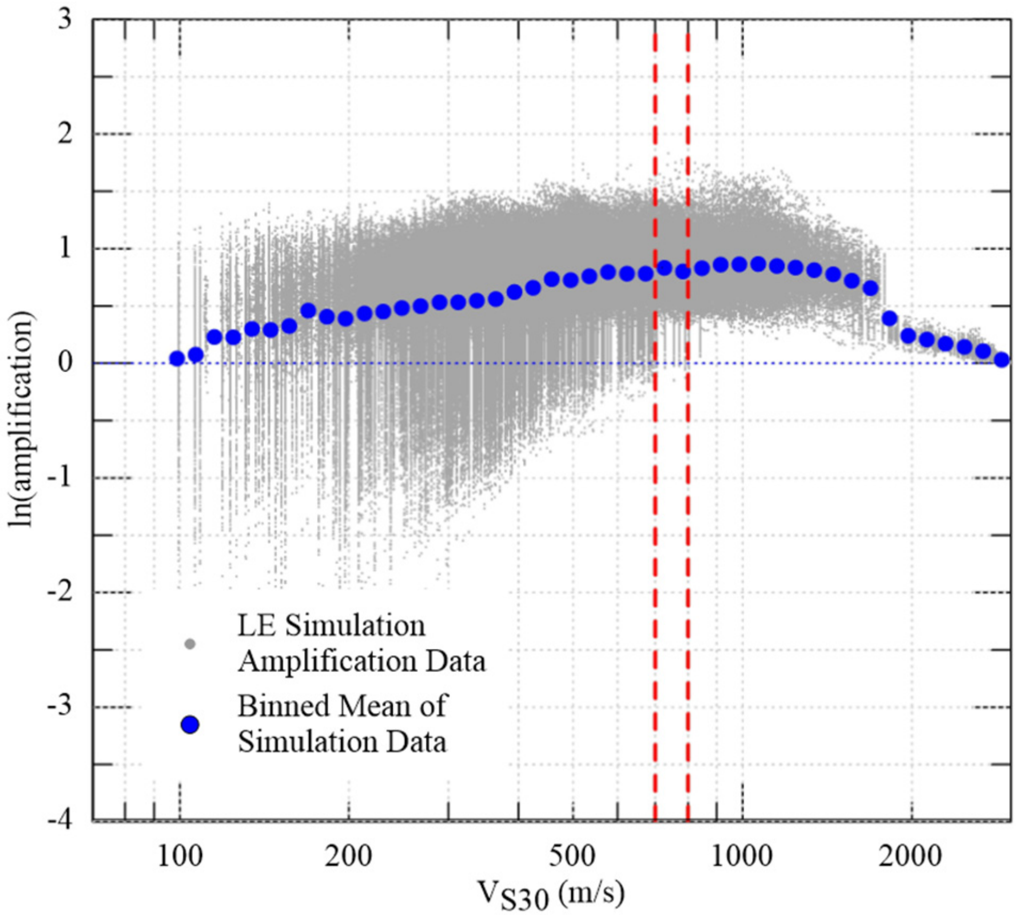

Figure 3.1 **Linear viscoelastic (LE) simulation amplification data and binned mean of simulation data at oscillator period of 0.001 sec. The red lines denotes the data range used to calculate 760/3000 correction value.**

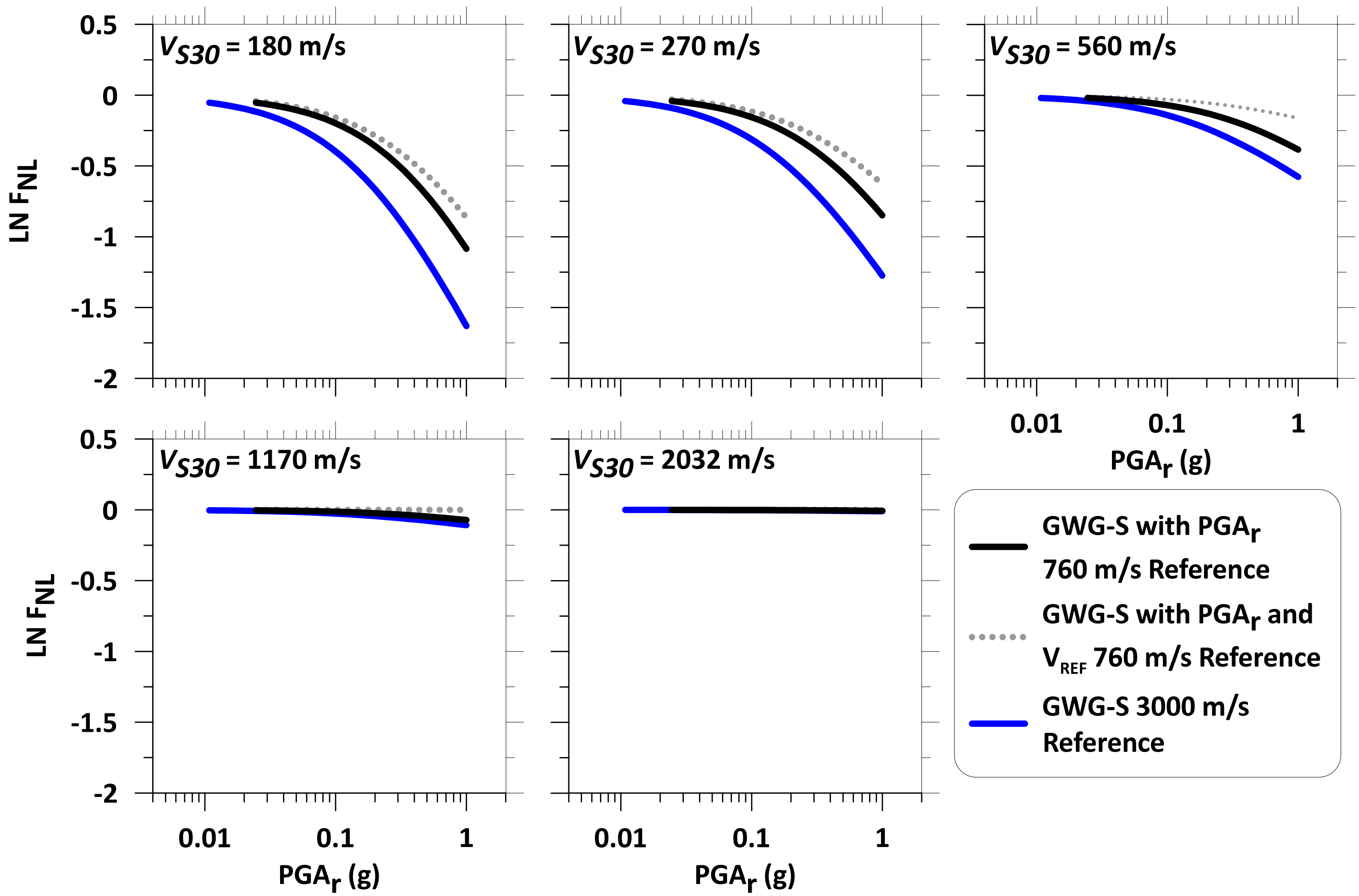

Figure 3.2 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at *T* = 0.08 sec. The black line is the recommended nonlinear amplification model relative to 3 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

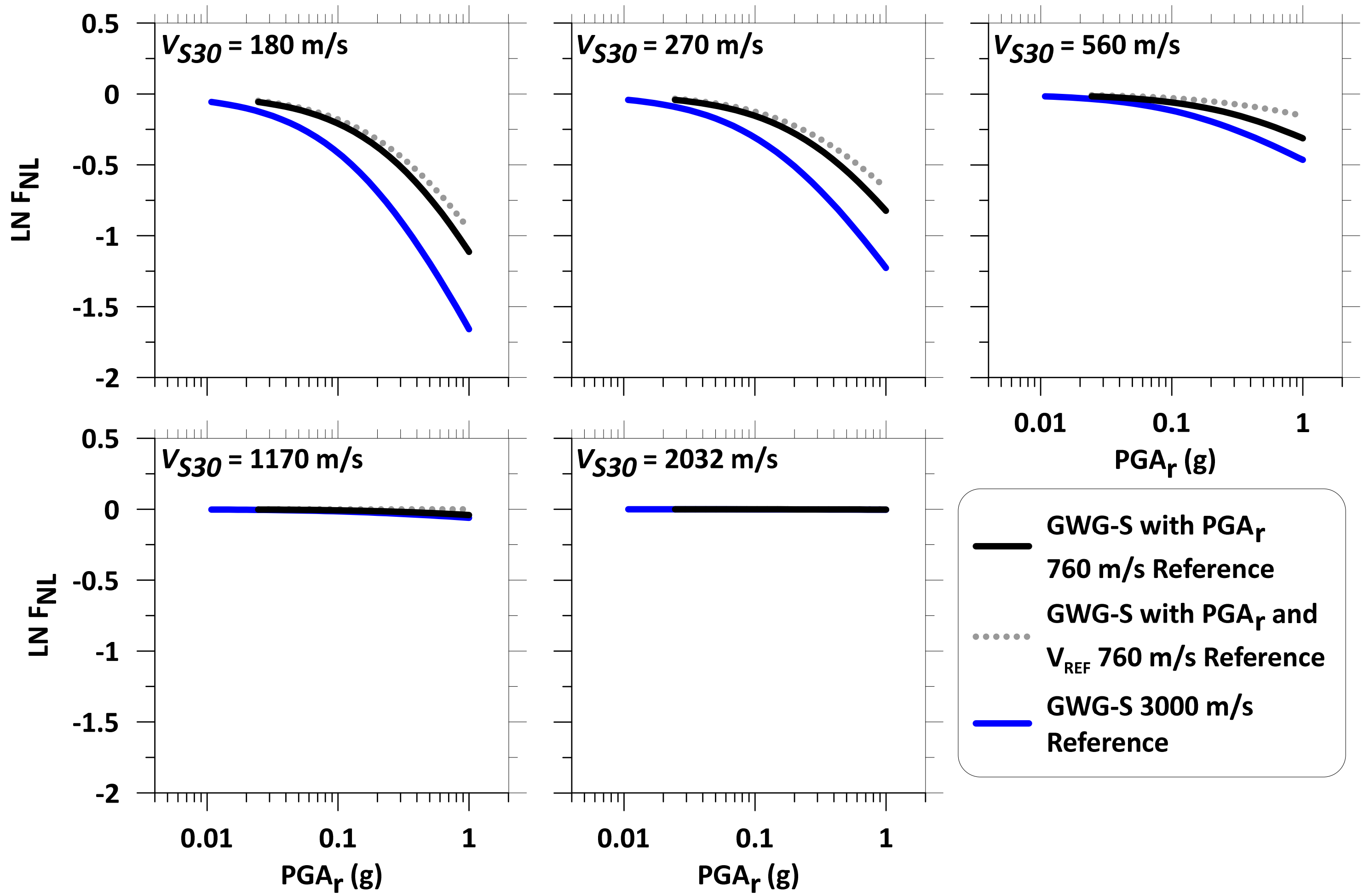

Figure 3.3 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 0.1 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

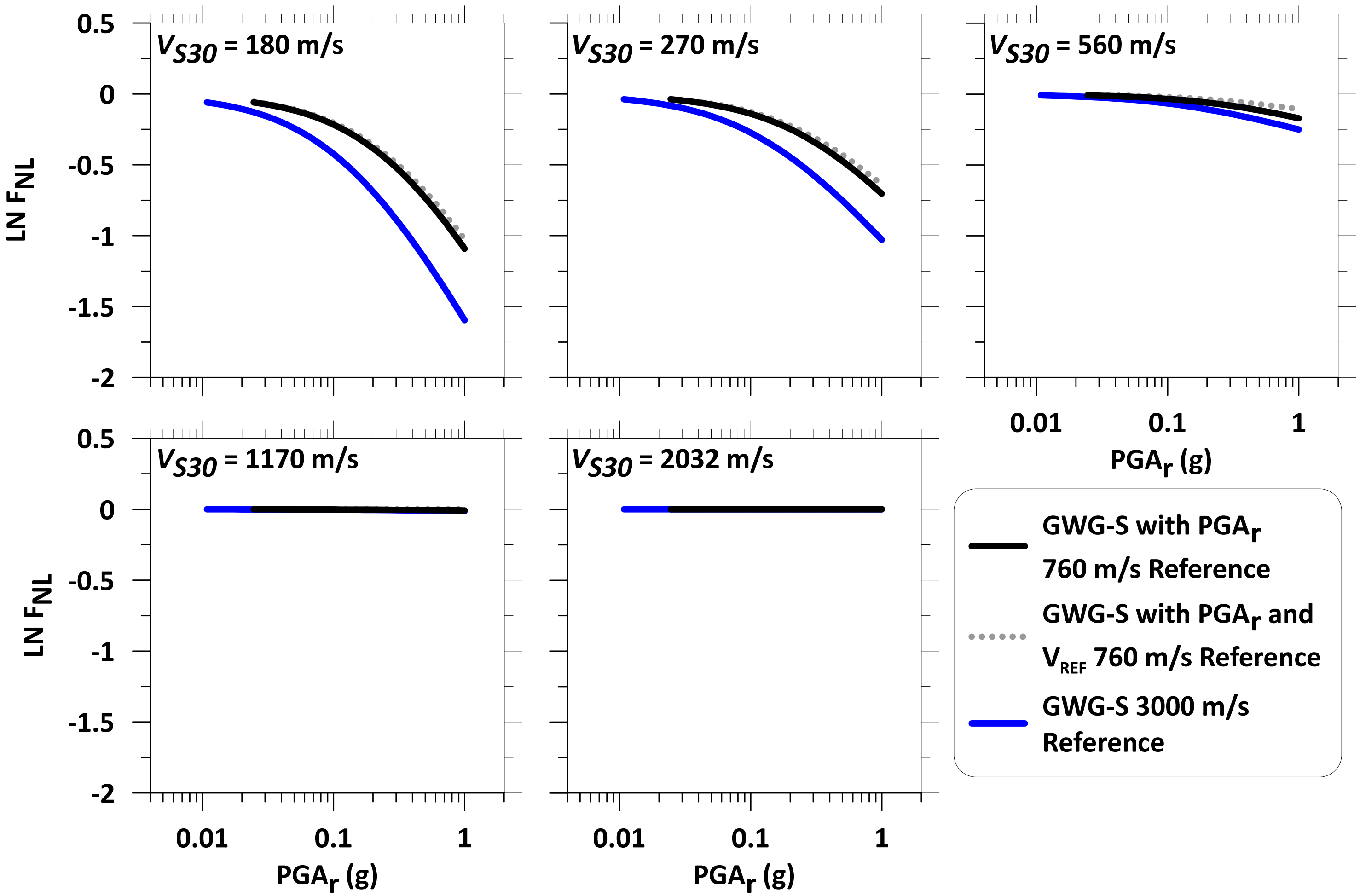

Figure 3.4 **Recommended GWG-S Response Spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 0.2 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.**

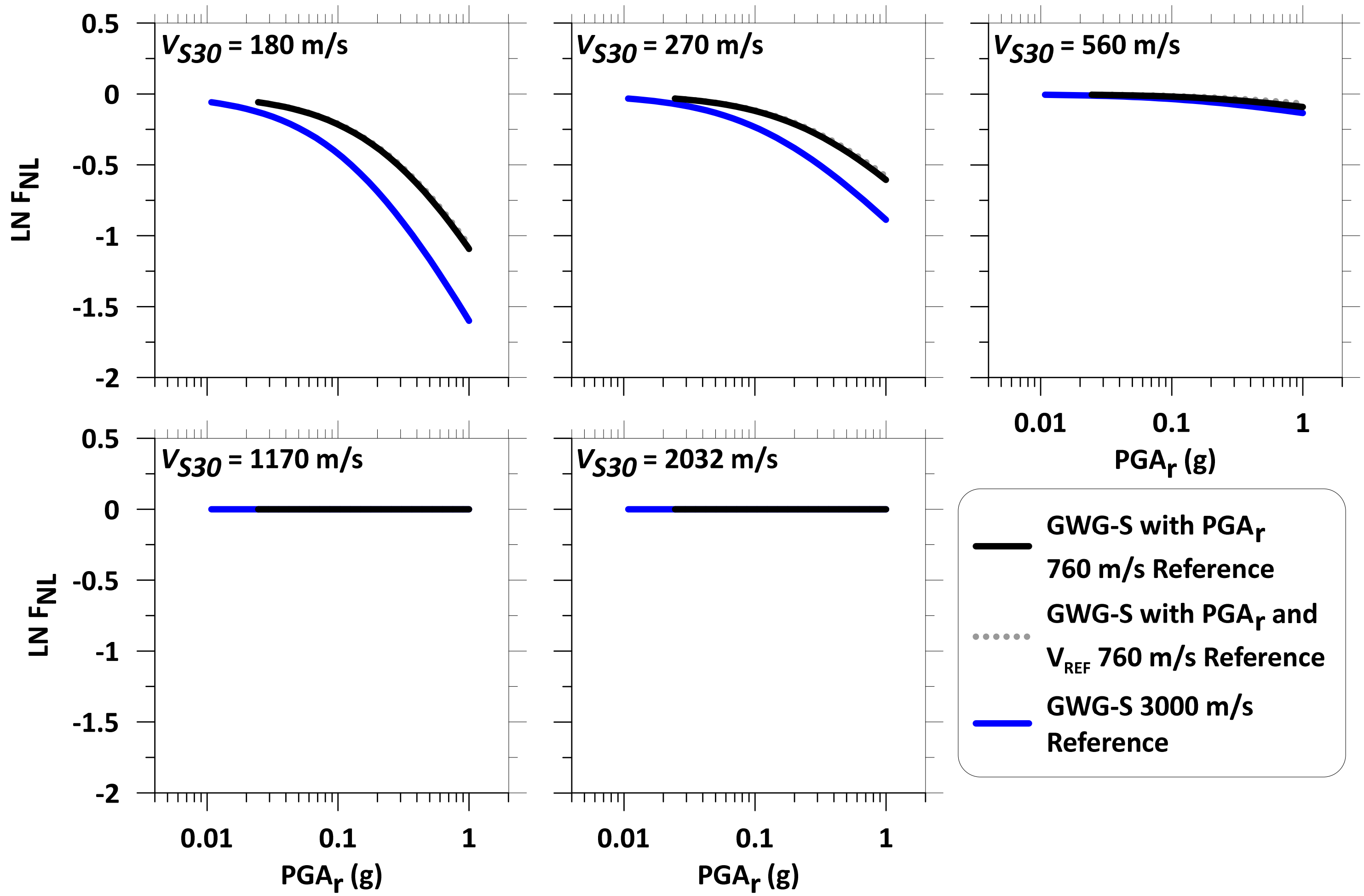

Figure 3.5 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at *T* = 0.3 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

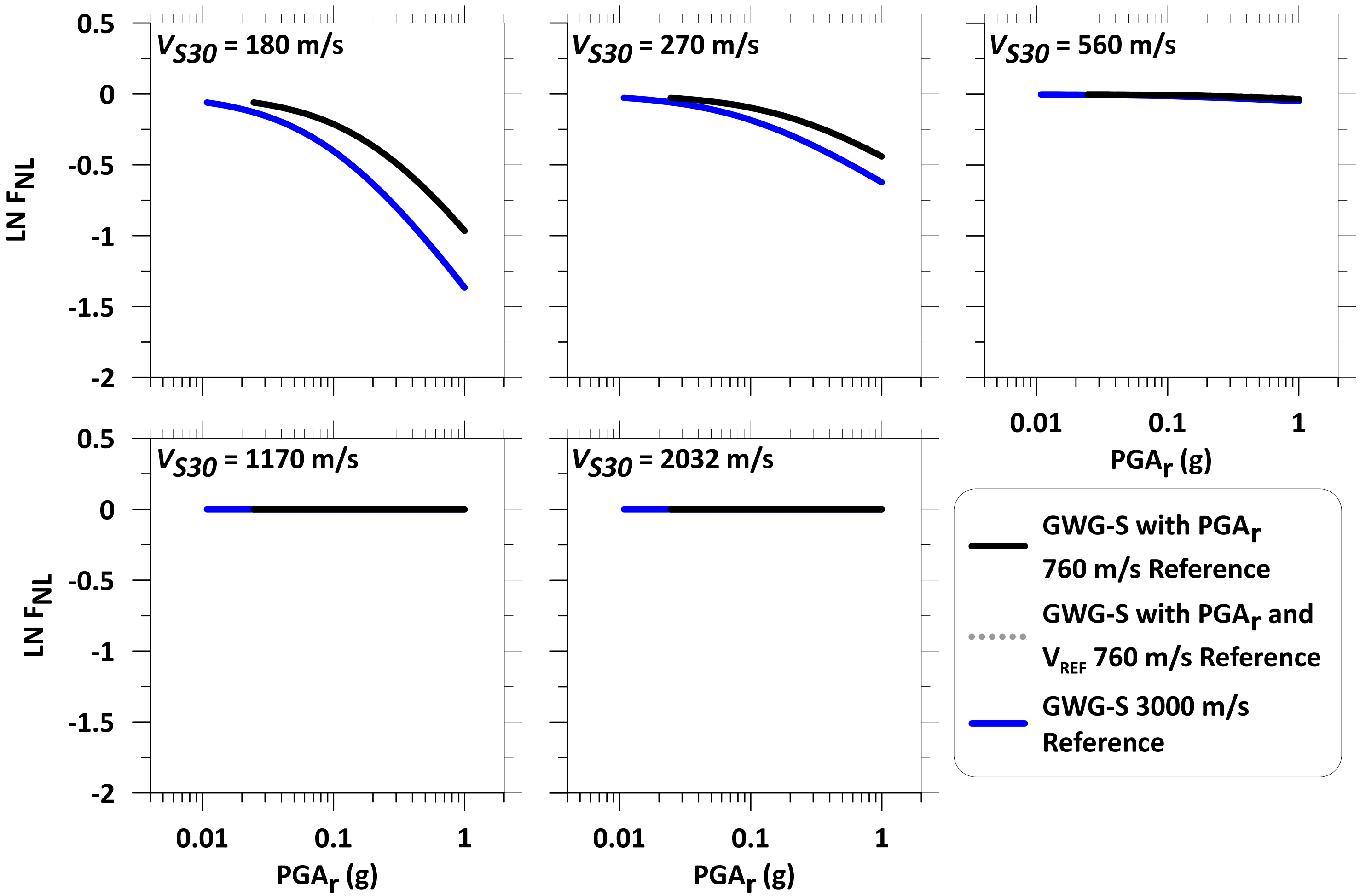

Figure 3.6 **Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at *T* = 0.4 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.**

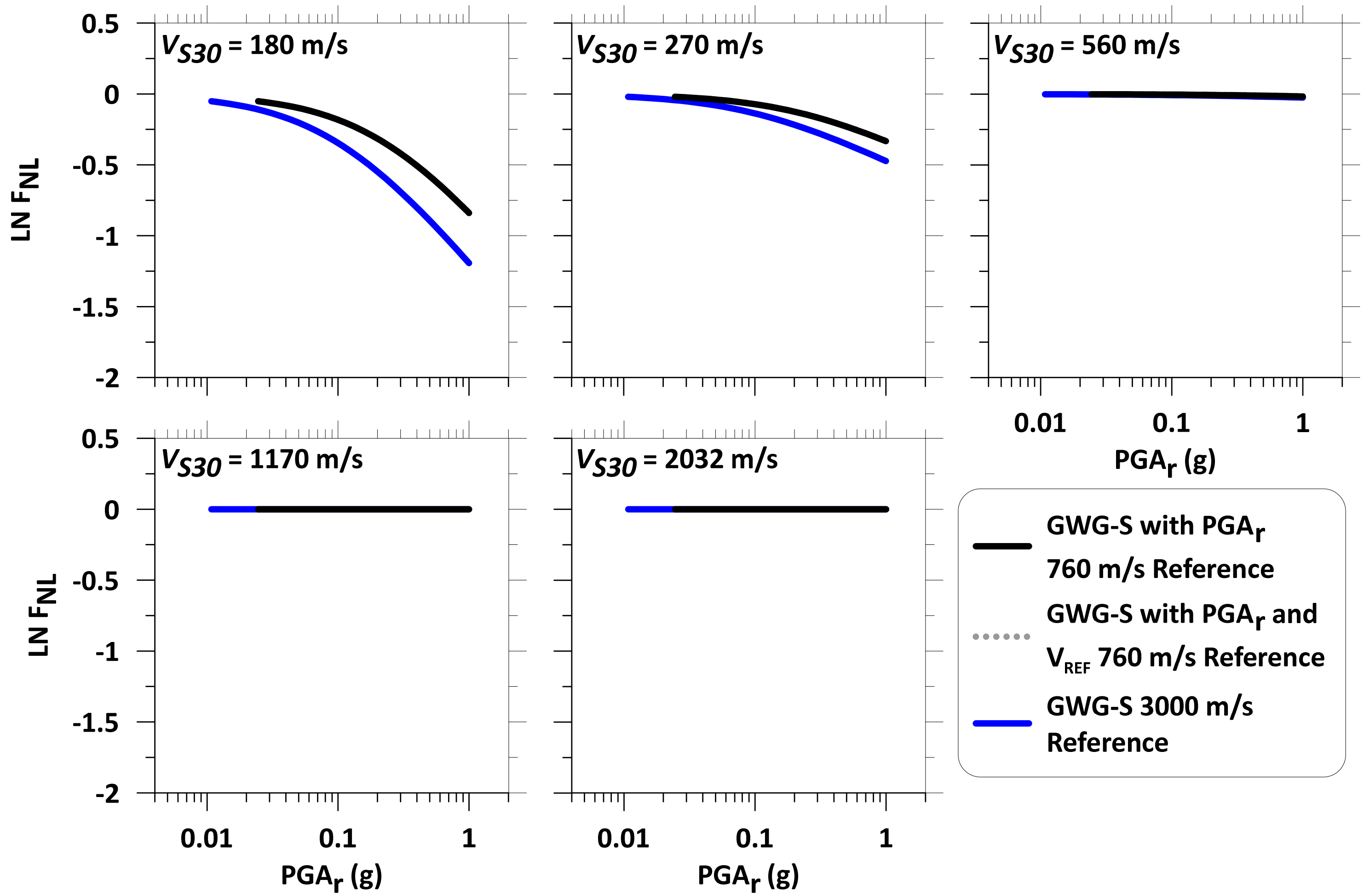

Figure 3.7 Recommended GWG-S Response Spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 0.5 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

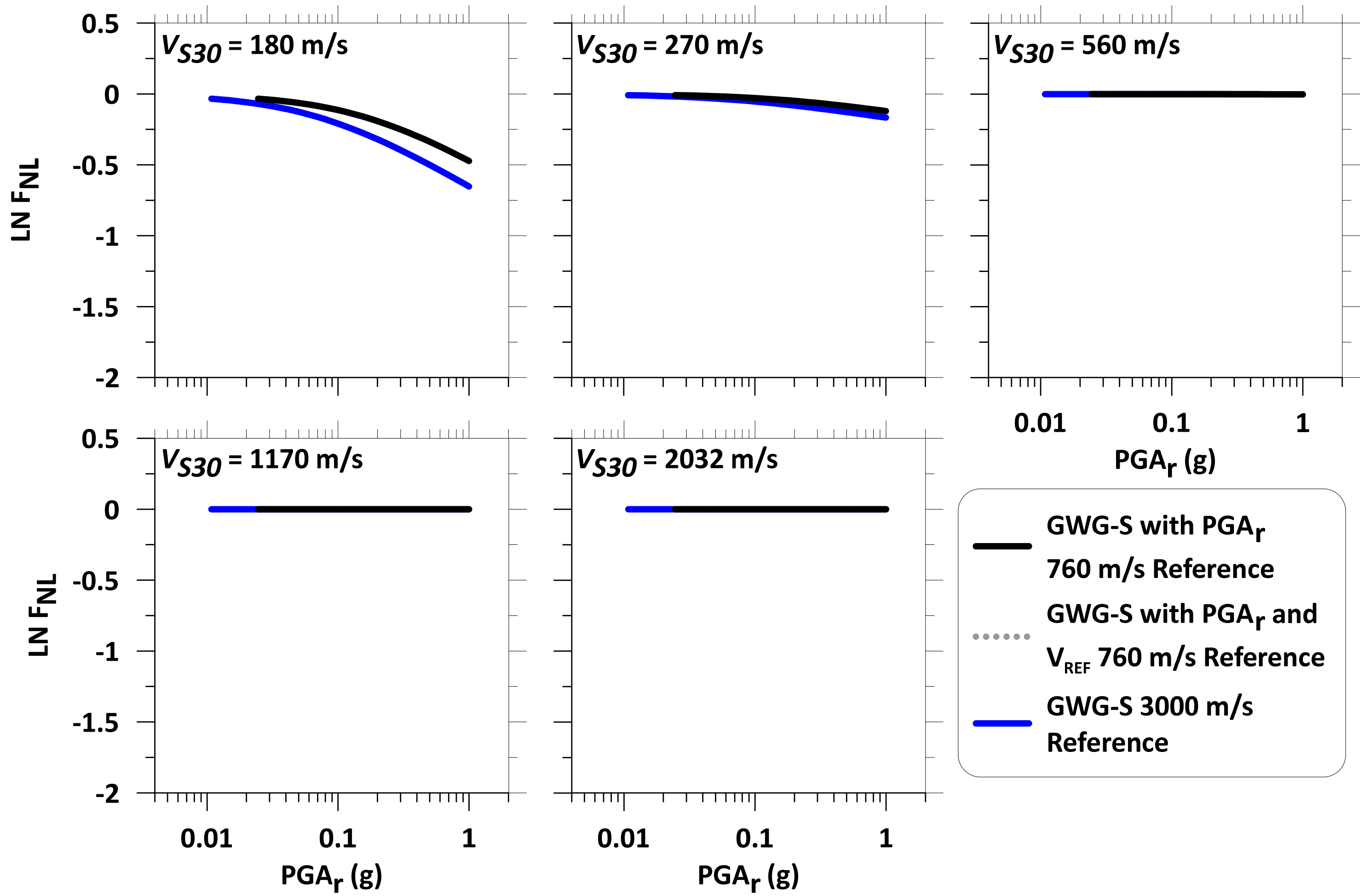

Figure 3.8 Recommended GWG-S Response Spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 0.8 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

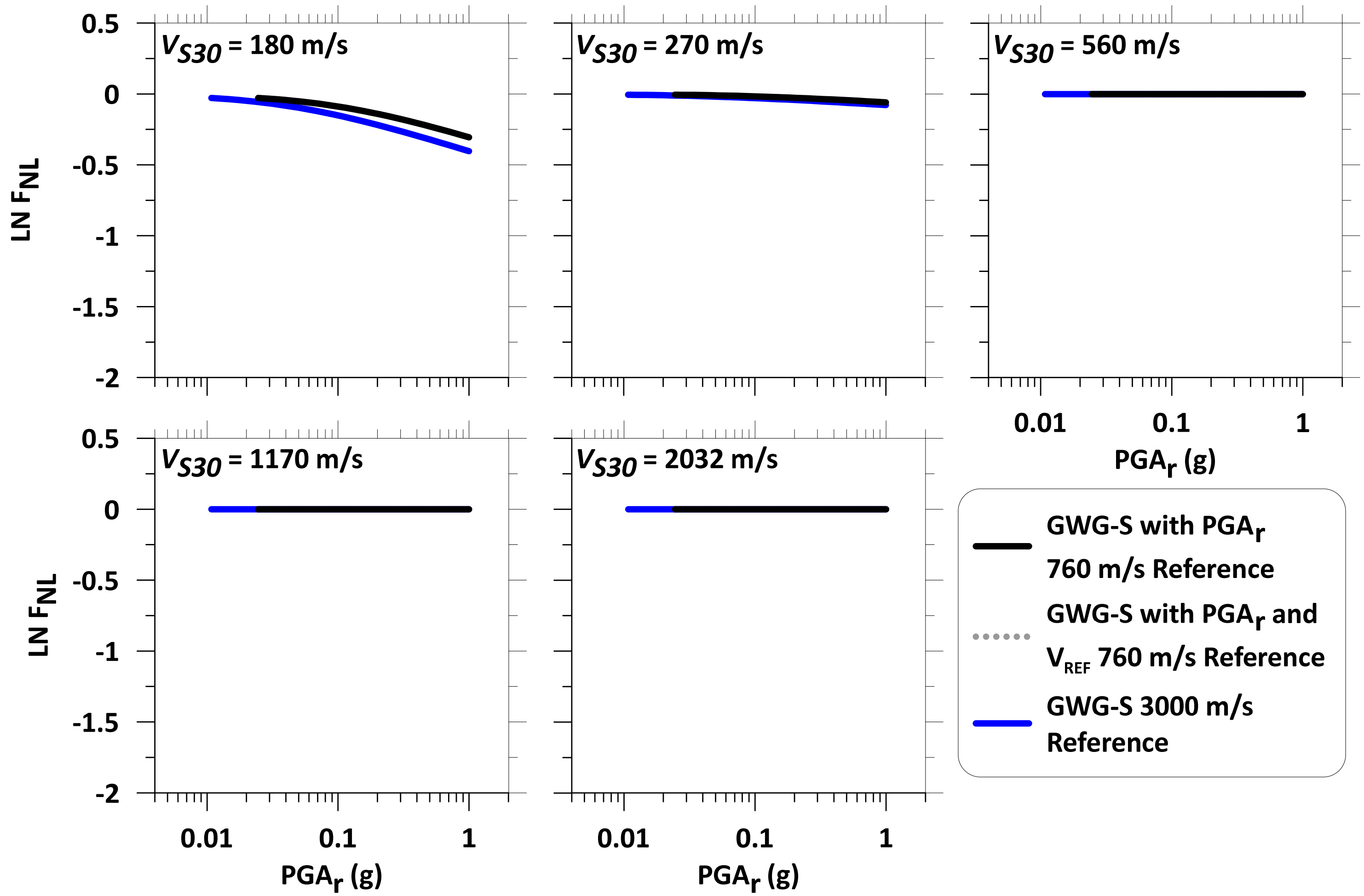

Figure 3.9 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 1.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

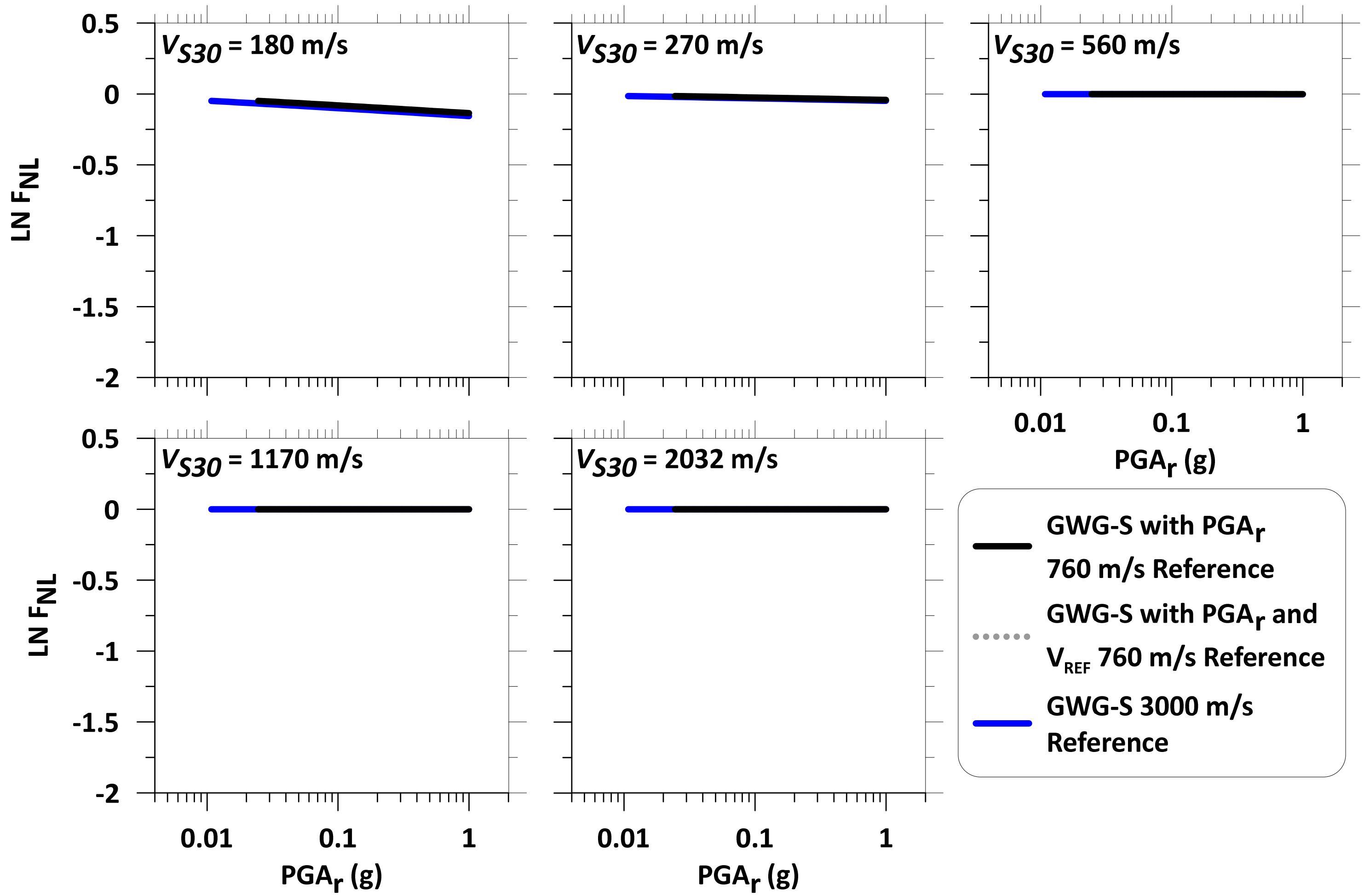

Figure 3.10 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 2.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

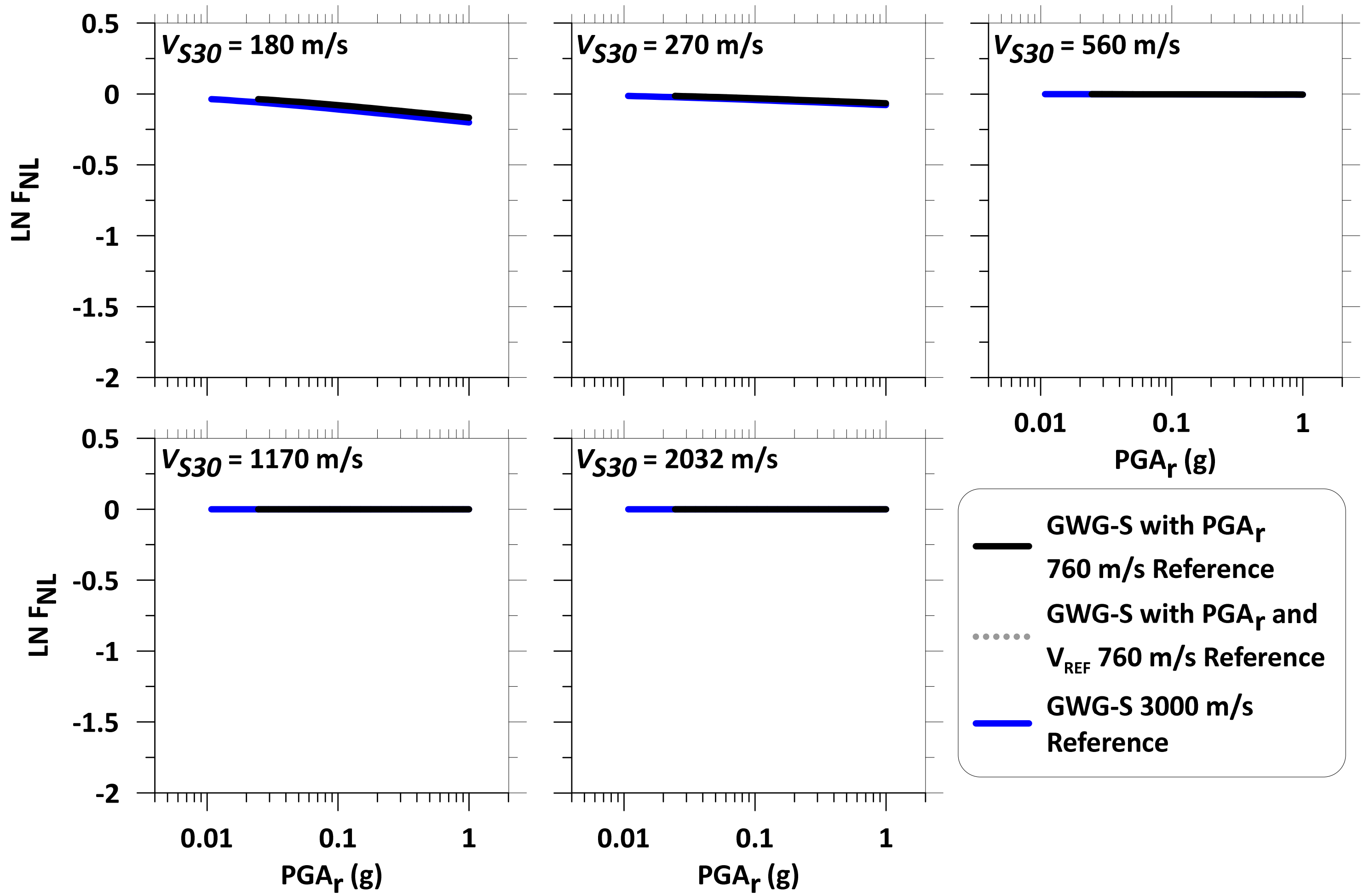

Figure 3.11 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 3.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

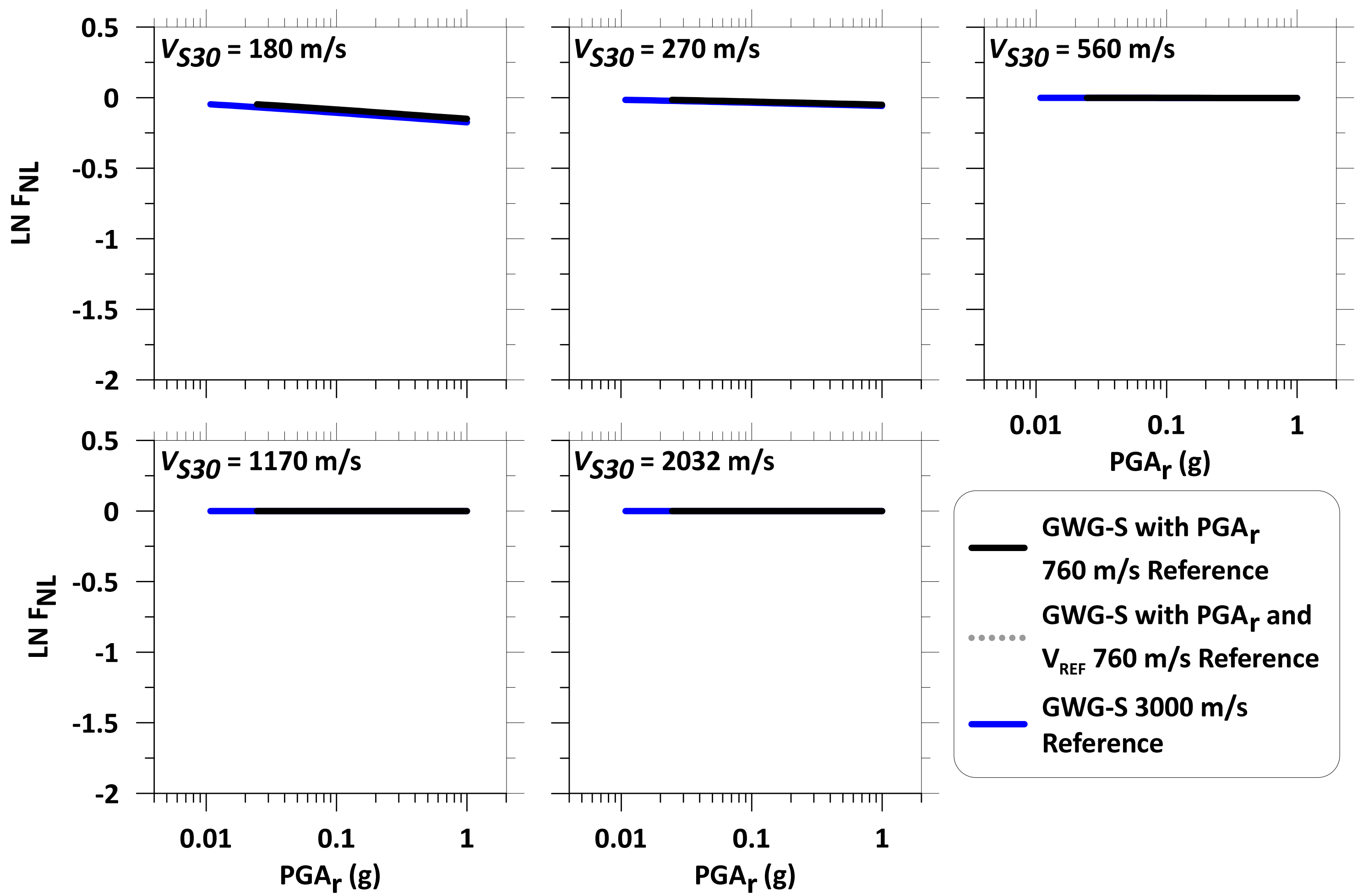

Figure 3.12 Recommended GWG-S Response Spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 4.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

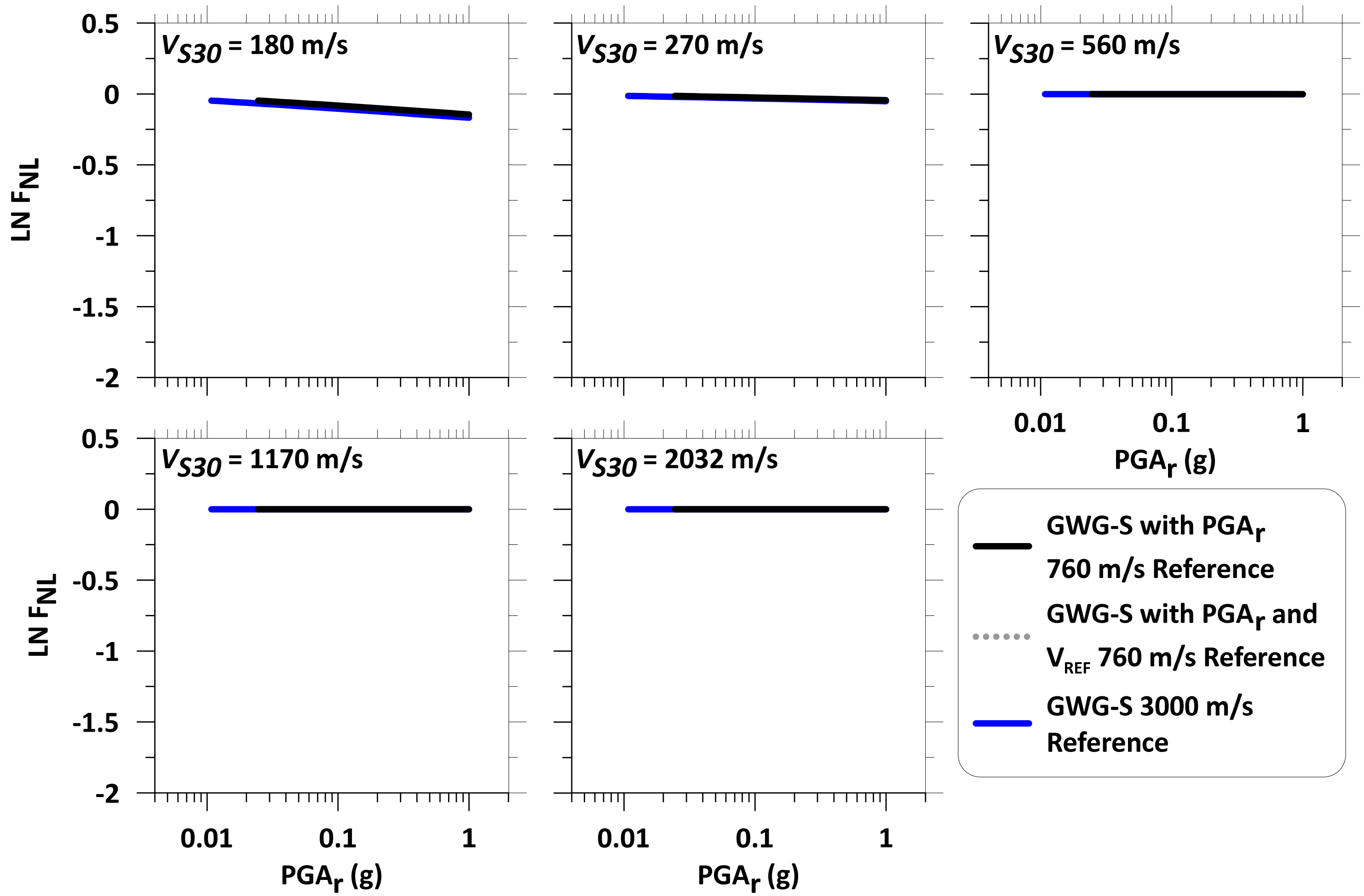

Figure 3.13 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 5.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

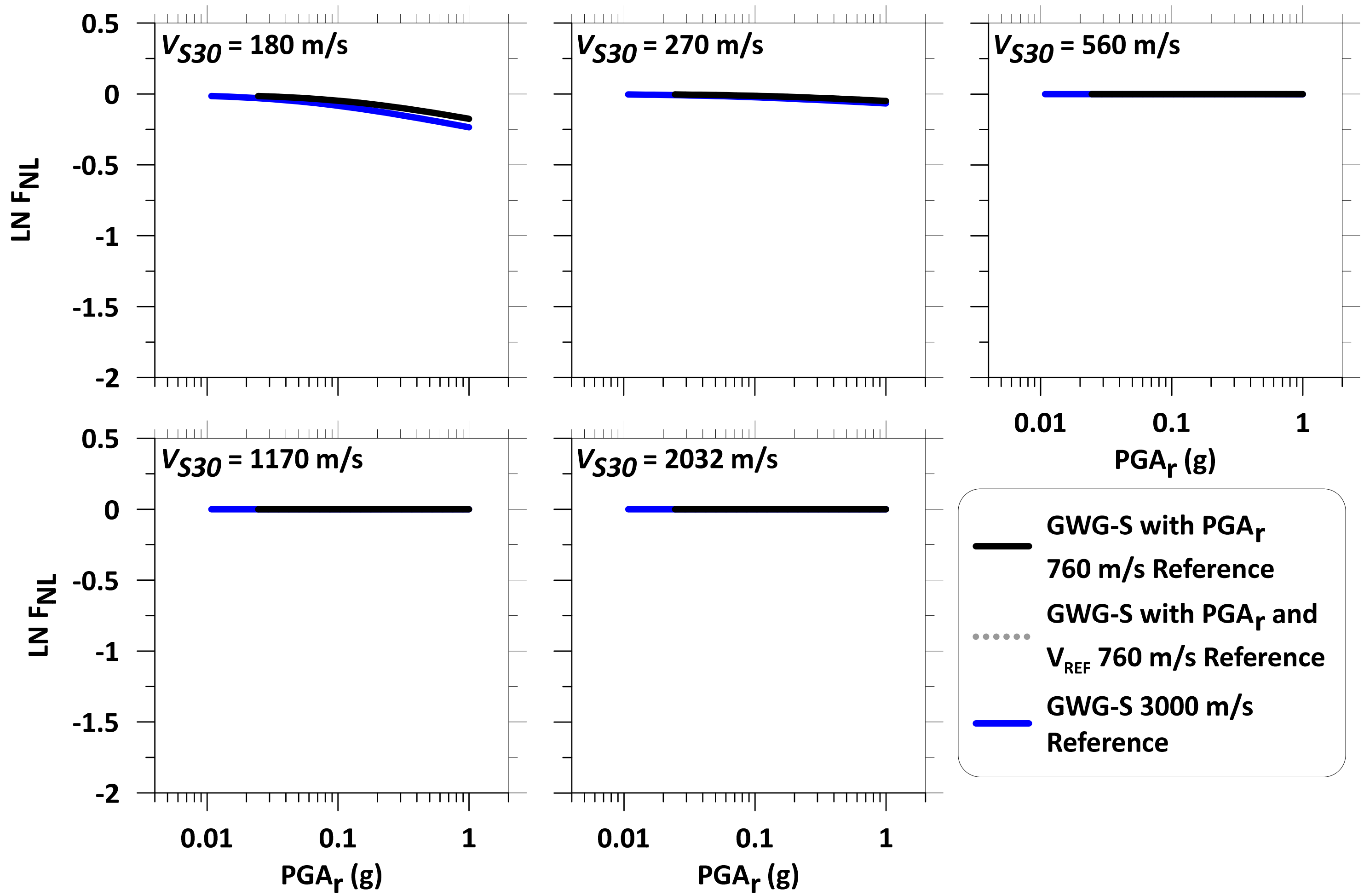

Figure 3.14 Recommended GWG-S response spectrum nonlinear amplification model estimations relative to 3000 m/sec (blue line) and estimations by two approaches relative to 760 m/sec at T = 10.0 sec. The black line is the recommended nonlinear amplification model relative to 760 m/sec from the GWG-S model with converted PGA, and the dotted gray line is the GWG-S nonlinear amplification model relative to 760 m/sec from converted V_{ref} and PGA.

3.2.3 PEA Nonlinear Model

The Darragh et al. [2015] GMM developed as a part of NGA-East uses equivalent linear site response simulations to calibrate the linear and nonlinear site effects. The equivalent linear site response simulations use V_S profiles representative of geologic regimes in CENA and modulus reduction and damping curves that have been calibrated to preserve high-frequency attenuation behavior at the ground surface, the EPRI Peninsular Region curves from Silva et al. [1997]. Amplification in the Darragh et al. [2015] simulations is computed relative to a V_S = 3000 m/sec reference-rock condition.

The component of nonlinear site amplification in the Darragh. et al. [2015] GMM can be computed by comparing the change in the equivalent linear site amplification as a function of PGA. The previously mentioned GWG-S model compares the intensity-independent linear elastic site response with nonlinear site response simulations to compute nonlinear amplification. Similarly, the equivalent linear site response calculations for low PGA values in the Darragh et al. [2015] simulations will show little site nonlinearity and can be compared to the equivalent linear site amplification simulations for larger PGA values for computation of nonlinear site amplification. The nonlinear amplification computed from the Darragh et al. [2015] simulations is referred to as the PEA model.

The PEA model is limited in usage compared to the GWG-S model because it features nonlinear site amplification calculated at discrete values of V_{S30} and PGA. No functional form is provided for the PEA model. For these reasons, the GWG-S model is preferred to the PEA model. However, the PEA model is valuable for comparison to the GWG-S model as it is developed independently from separate simulations and authors and designed similarly for use in modeling nonlinear site effects in CENA.

3.3 UNCERTAINTY IN RESPONSE SPECTRUM NONLINEAR AMPLIFICATION MODEL

The GWG-S models relative to 3000 m/sec and 760 m/sec in Sections 3.2.1 and 3.2.2 are the recommended median models for nonlinear site amplification. For these models, an epistemic uncertainty on the nonlinear amplification is recommended by including an estimate of uncertainty into the f_2 coefficient model term in Equation (2.2). The uncertainty on the f_2 model term, σ_{f2}, is estimated using judgement, with the objective of having a reasonable variation of nonlinear amplification across the period and V_{S30} range of interest. The uncertainty model recommended here was derived for use with the V_S = 3000 m/sec reference recommended median model. However, the uncertainty model produces reasonable bounds of behavior for the V_{S30} = 760 m/sec reference recommended median model and is judged to be appropriate for both recommended median models.

The uncertainty σ_{f2} has a piecewise functional form given in the Equation (2.5) developed from visual inspection of estimated nonlinear amplification and physical considerations of nonlinear site amplification given as:

- σ_{f2} is assumed to be constant for V_{S30} < 300 m/sec
- σ_{f2} decreases linearly in log-space for 300 m/sec ≤ V_{S30} < 1000 m/sec, and is zero at V_{S30} = 1000 m/sec and beyond.

This uncertainty model is described by a single parameter (i.e., σ_{f2} for V_{S30} < 300 m/sec), which is called as $\sigma_c = f(T)$ and is given in Table 2.1 for period values of 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8, 1.0, 2.0, 3.0, 4.0, 5.0, and 10.0 sec. The behavior of σ_{f2} as a function of V_{S30} range of 100 m/sec and 3000 m/sec at oscillator period value of 0.1 sec is presented visually in Figure 2.2.

The application of epistemic uncertainty model on recommended nonlinear amplification model is presented in Figure 3.15 through Figure 3.27 with the PGA-Gradient [Darragh et al. 2015] model, and recommended GWG-S nonlinear amplification models for oscillator periods of 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8, 1.0, 2.0, 3.0, 4.0, 5.0, and 10.0 sec. The resulting uncertainty range from the epistemic uncertainty model typically lies within the range of the binned Harmon [2017] simulation data with ±1 standard deviation and PEA model, suggesting that the range of model uncertainty is appropriate.

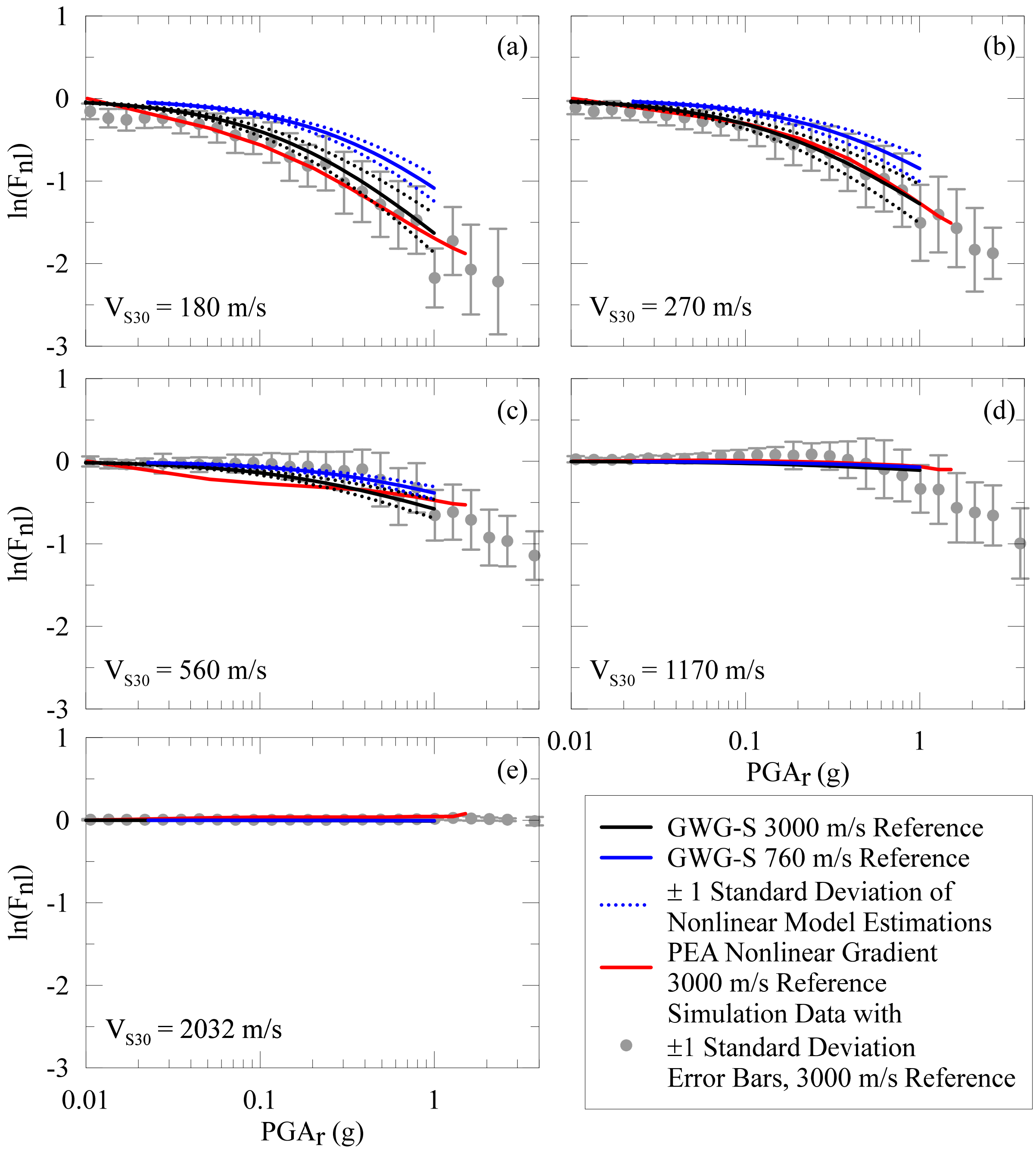

Figure 3.15 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.08 sec.**

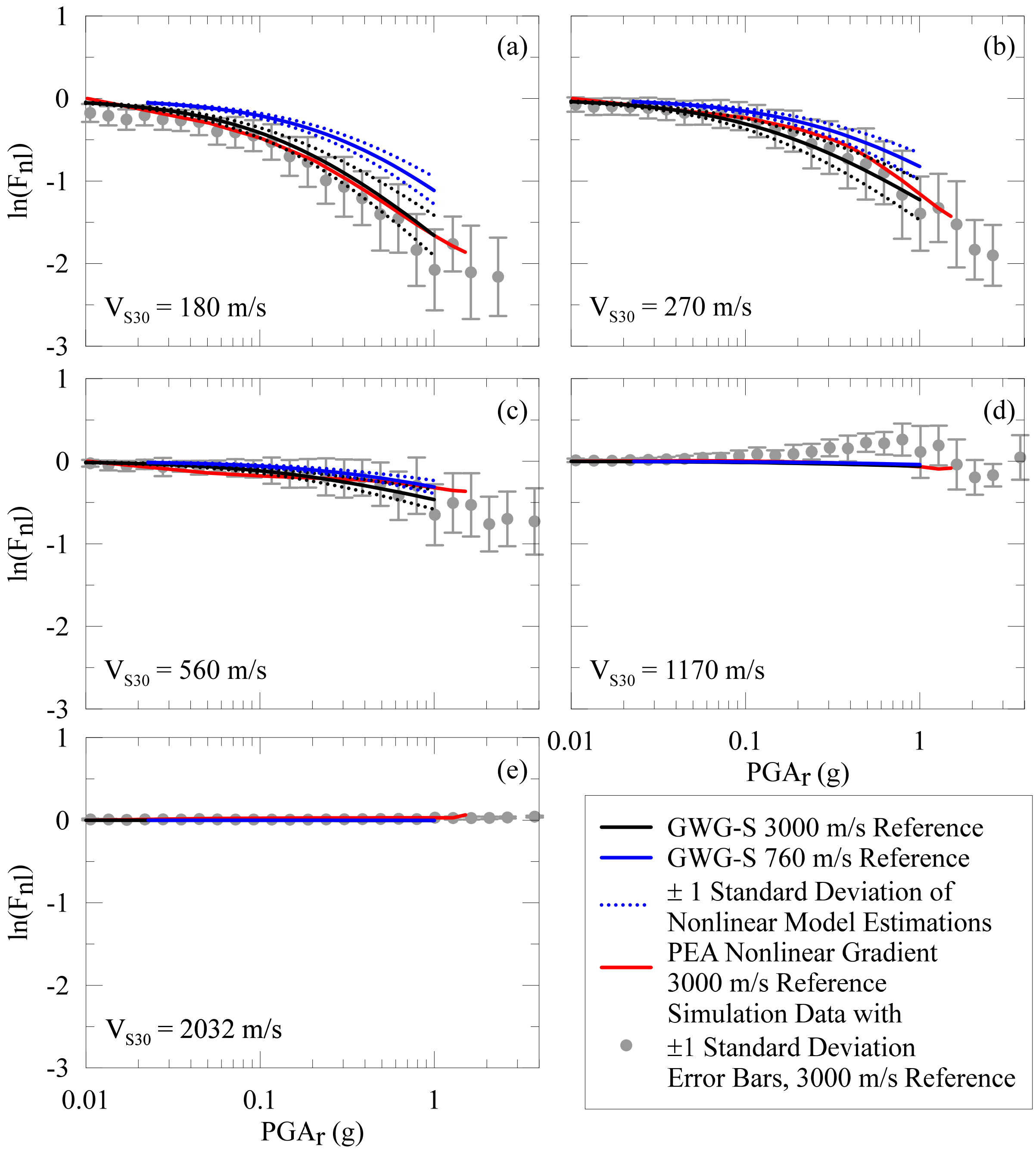

Figure 3.16 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.1 sec.**

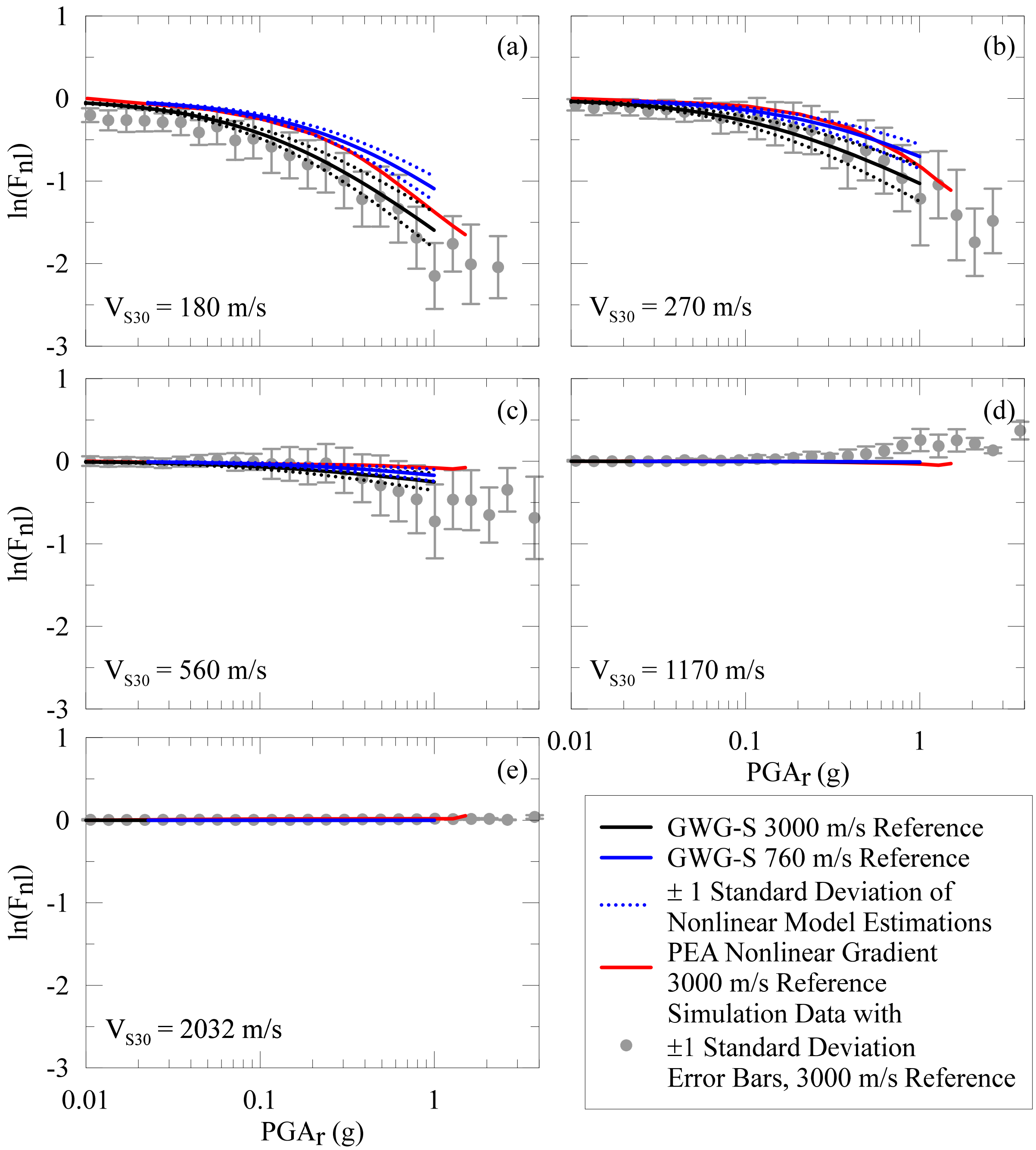

Figure 3.17 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.2 sec.**

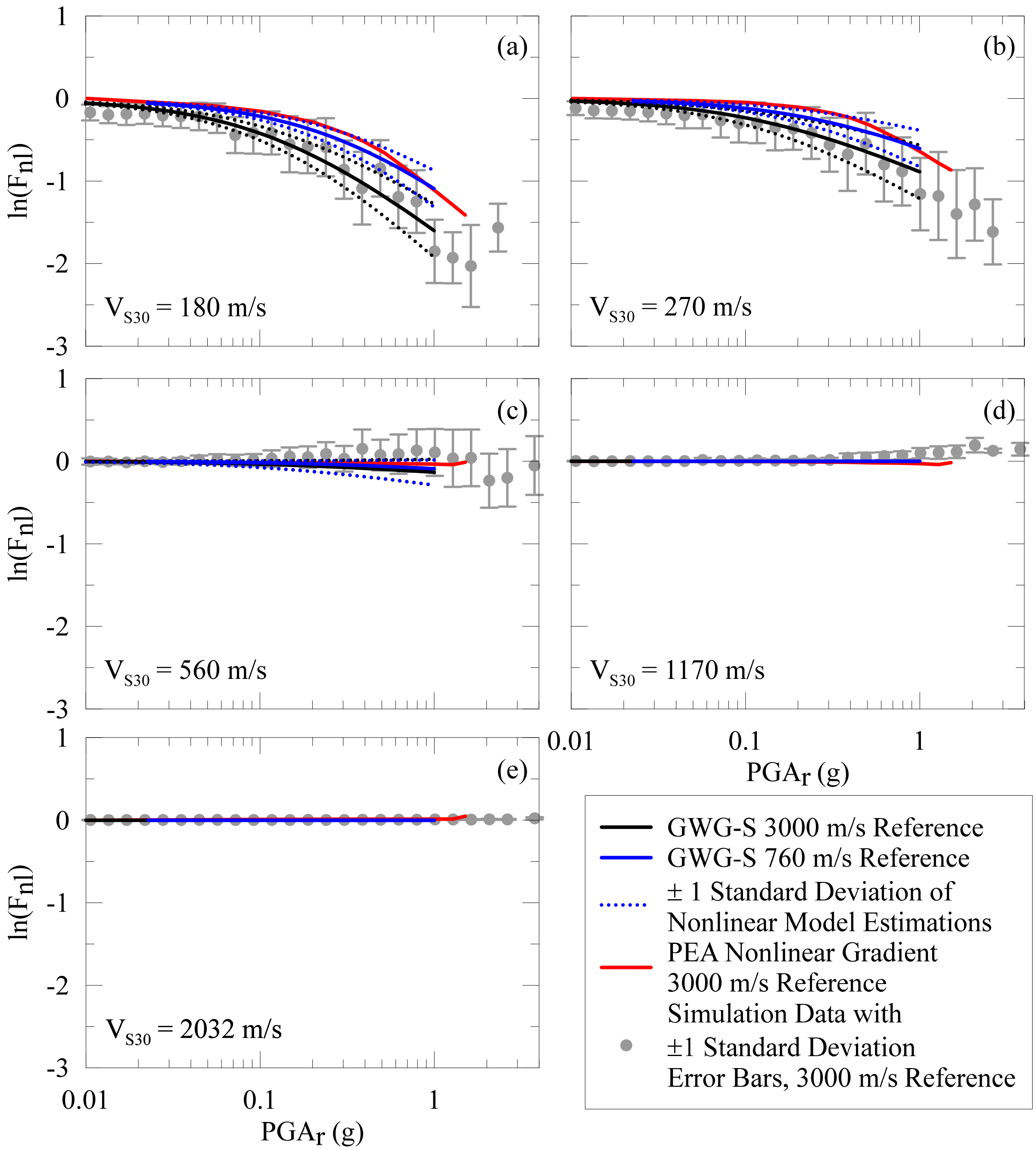

Figure 3.18 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.3 sec.**

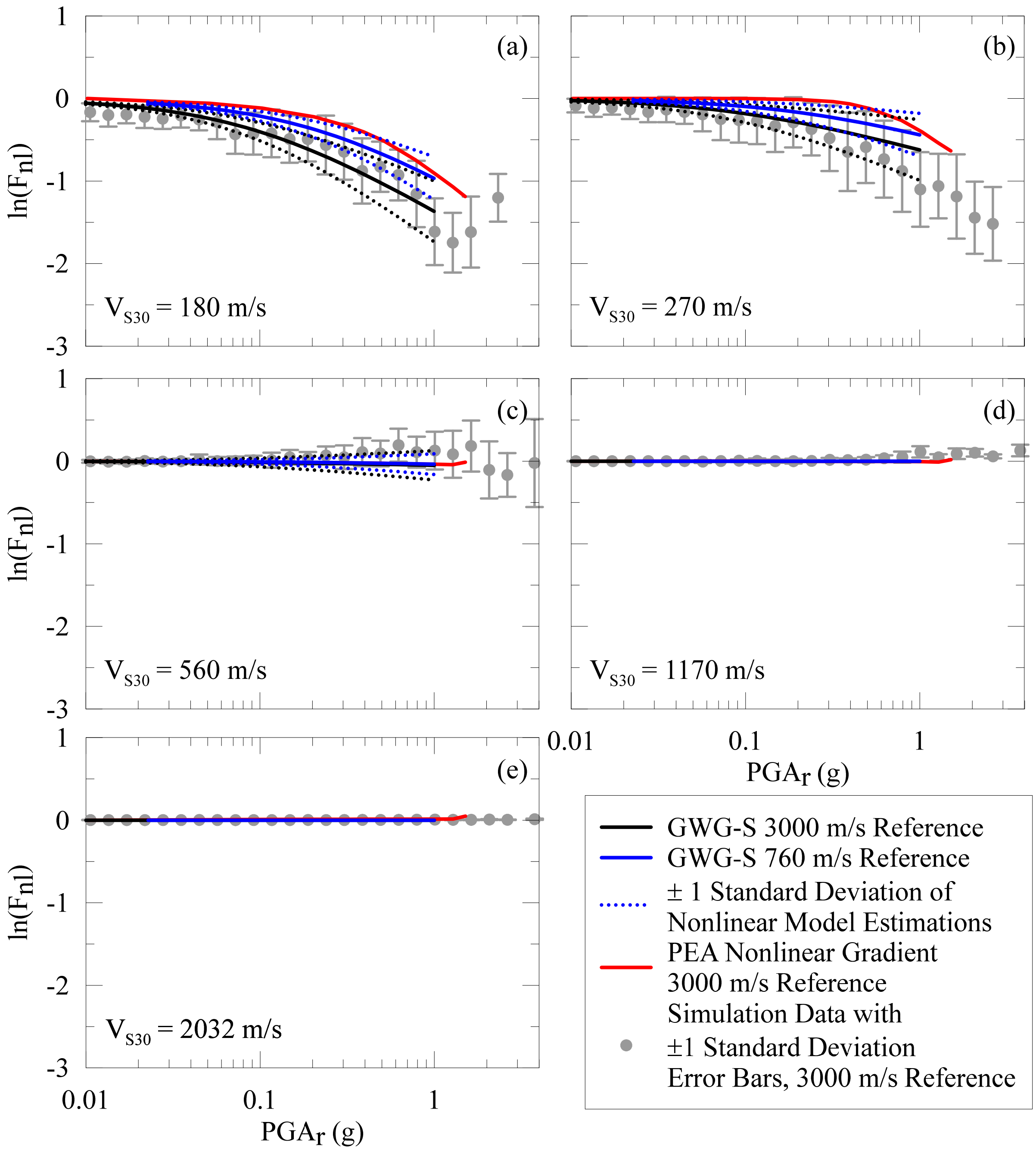

Figure 3.19 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.4 sec.**

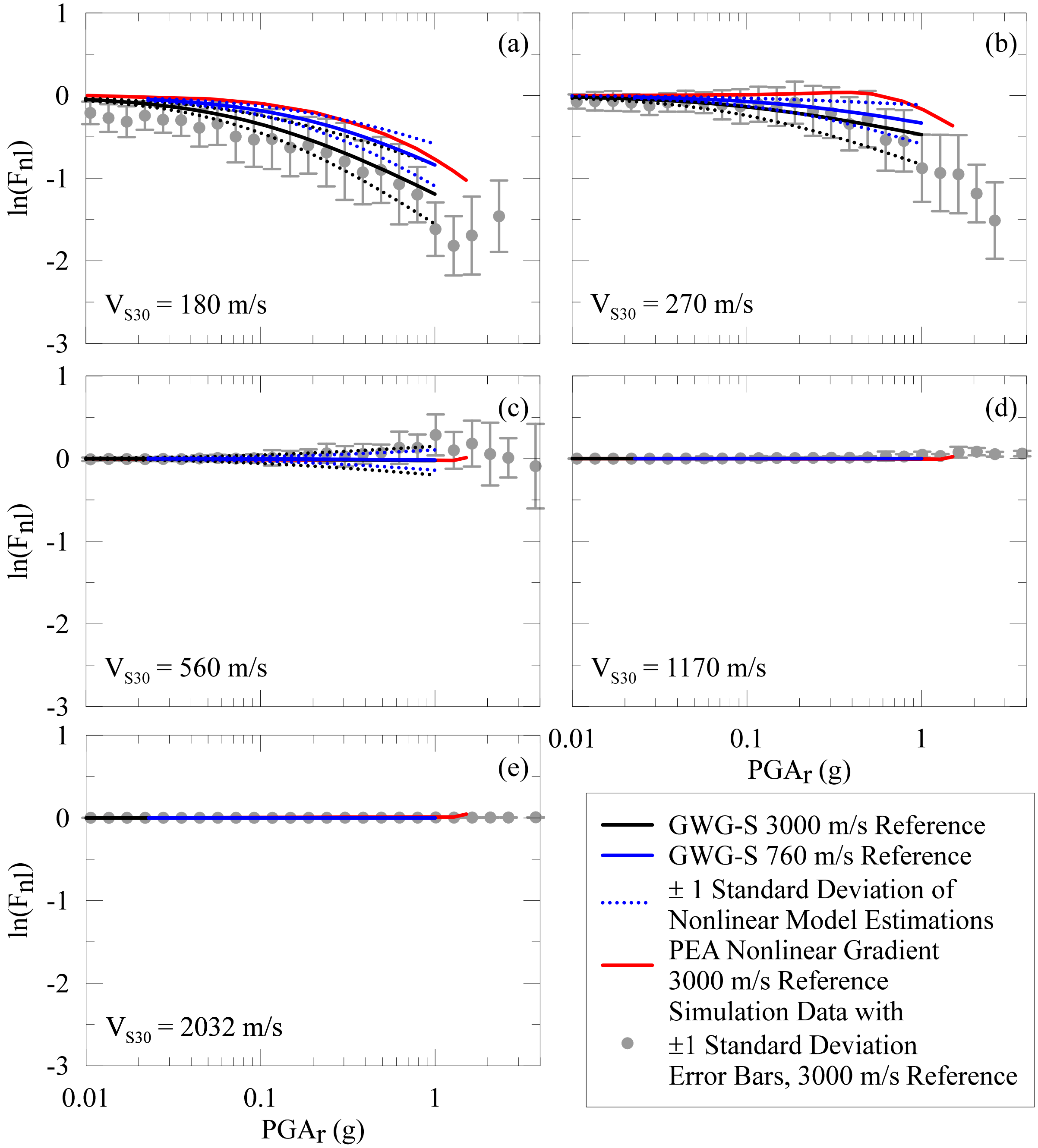

Figure 3.20 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.5 sec.**

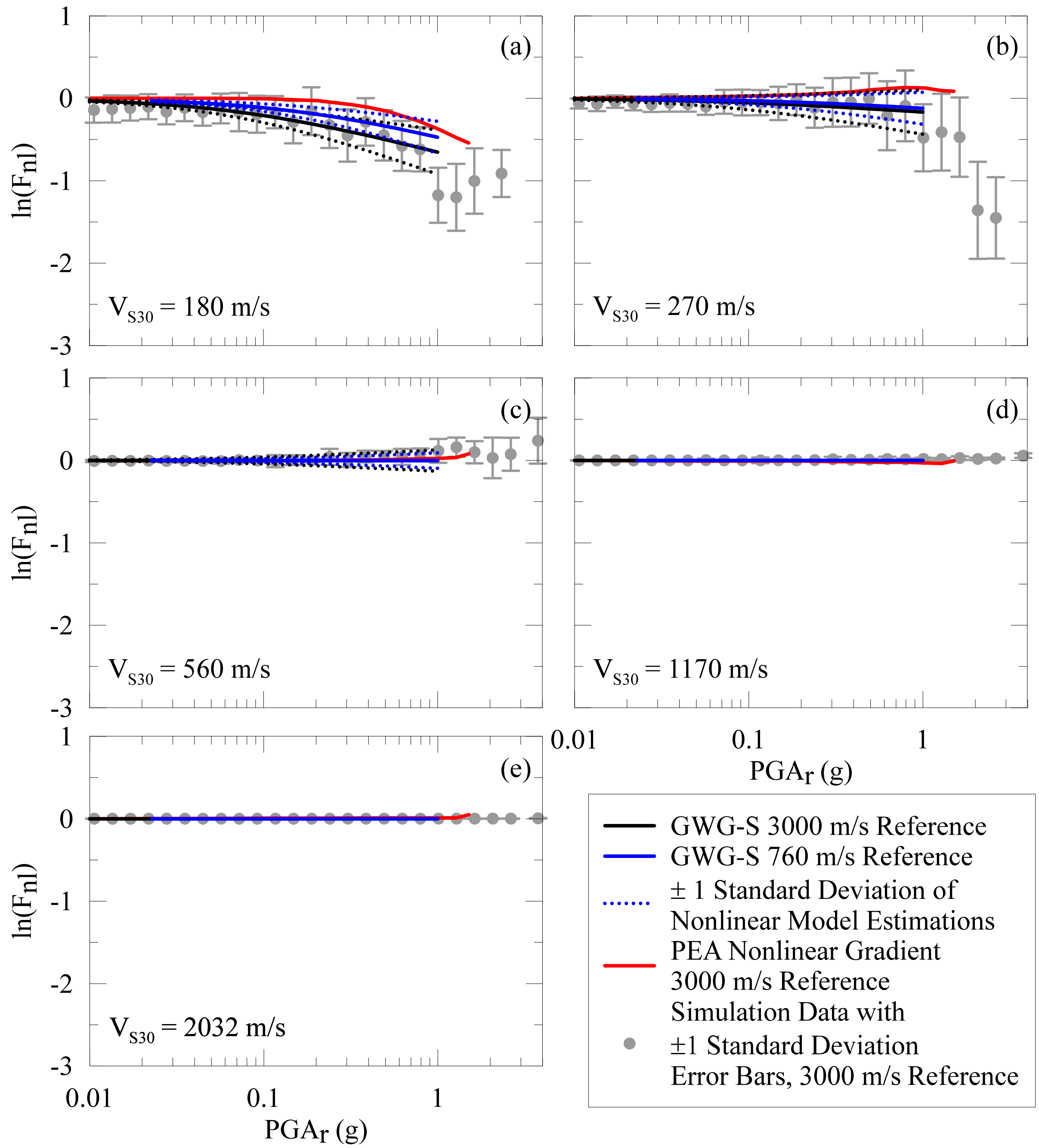

Figure 3.21 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 0.8 sec.**

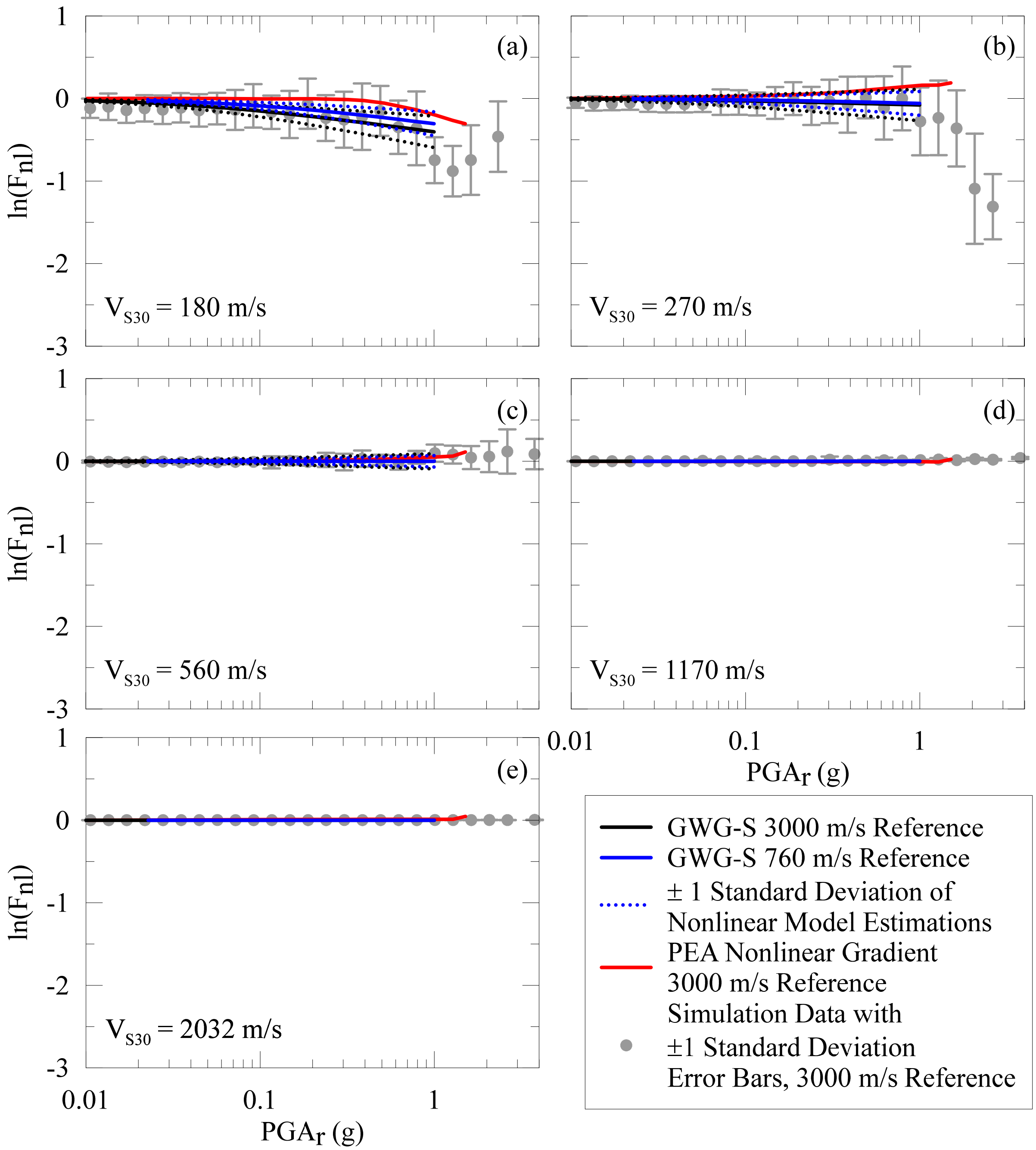

Figure 3.22 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 1.0 sec.**

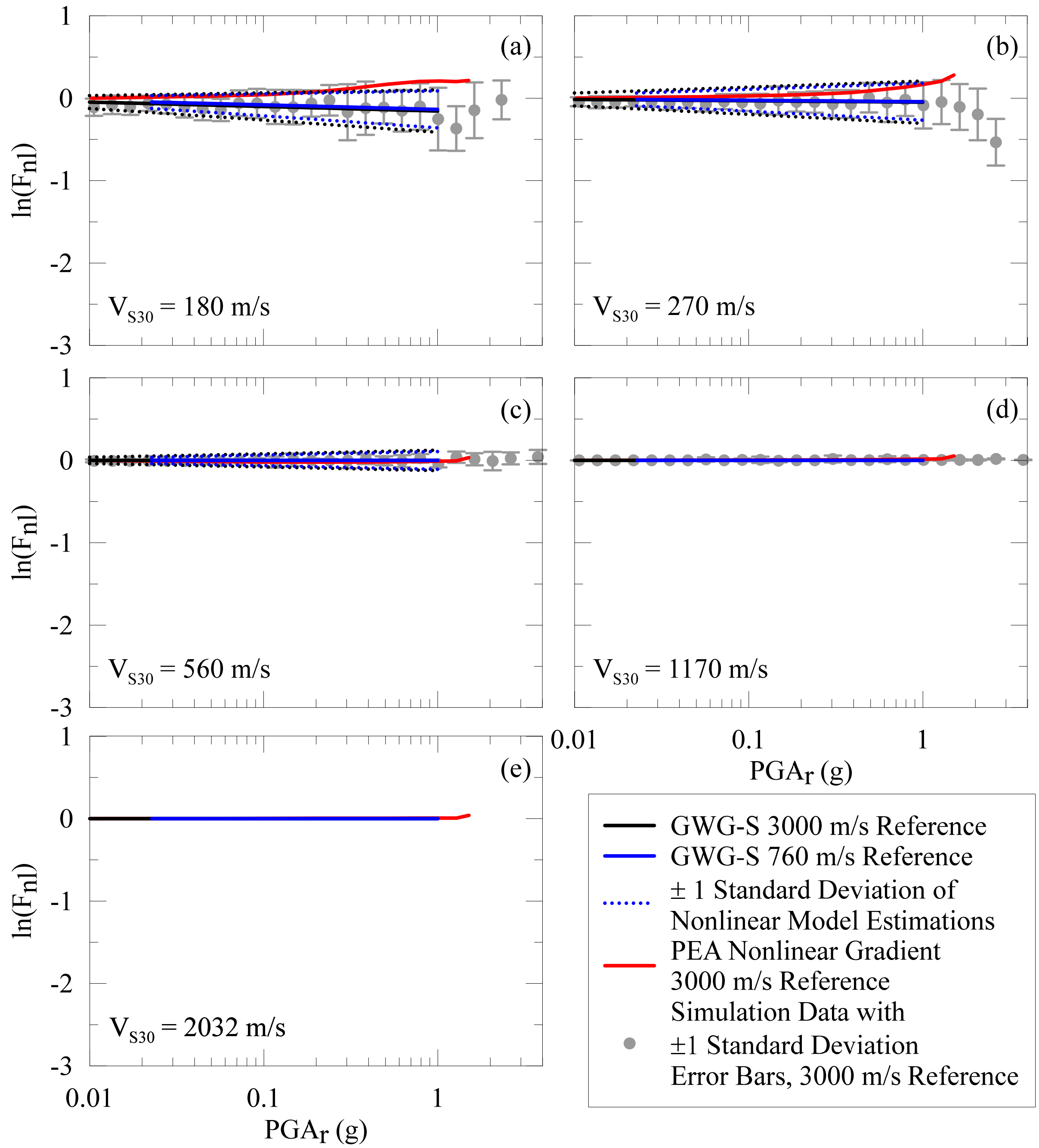

Figure 3.23 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 2.0 sec.**

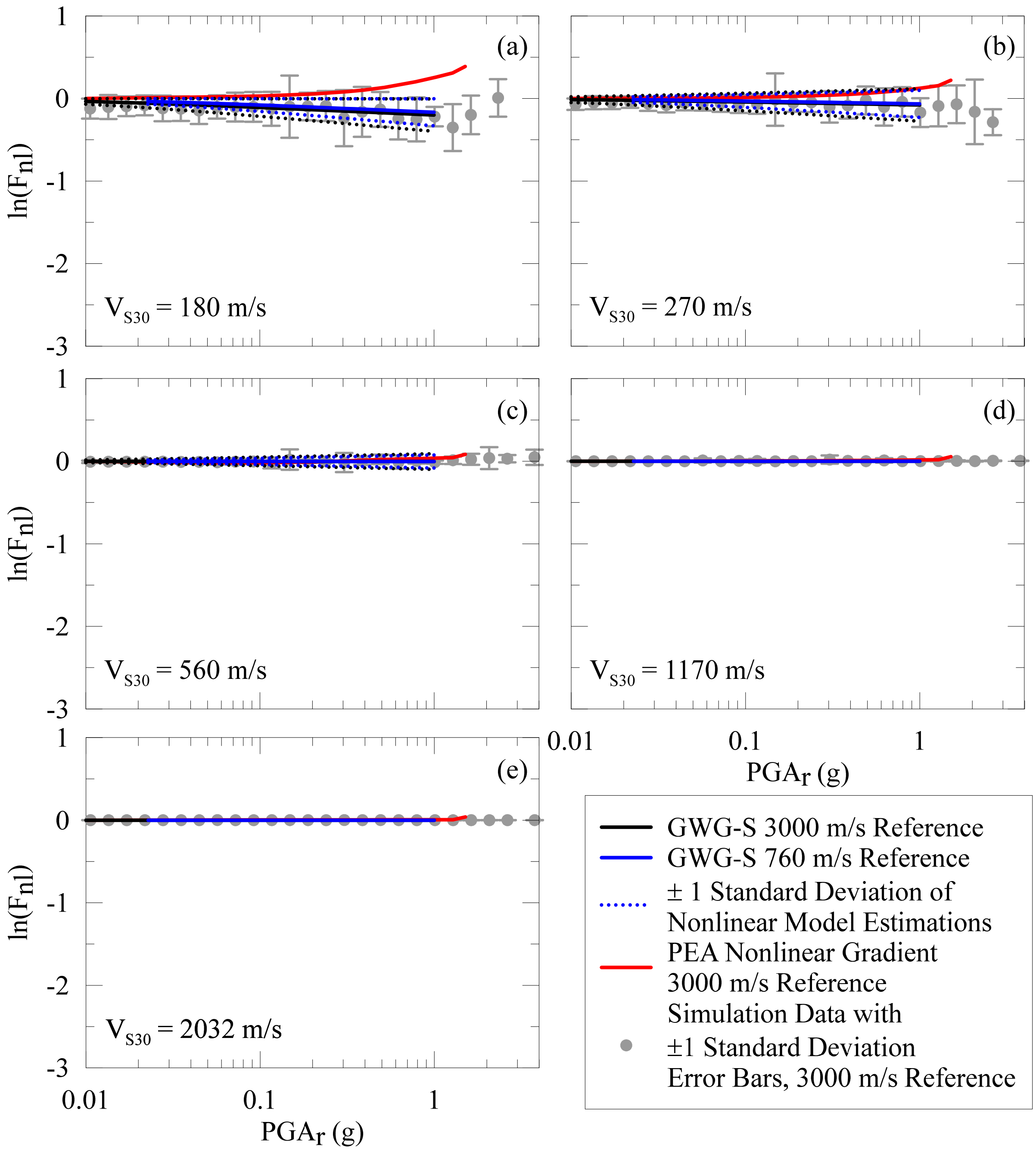

Figure 3.24 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 3.0 sec.**

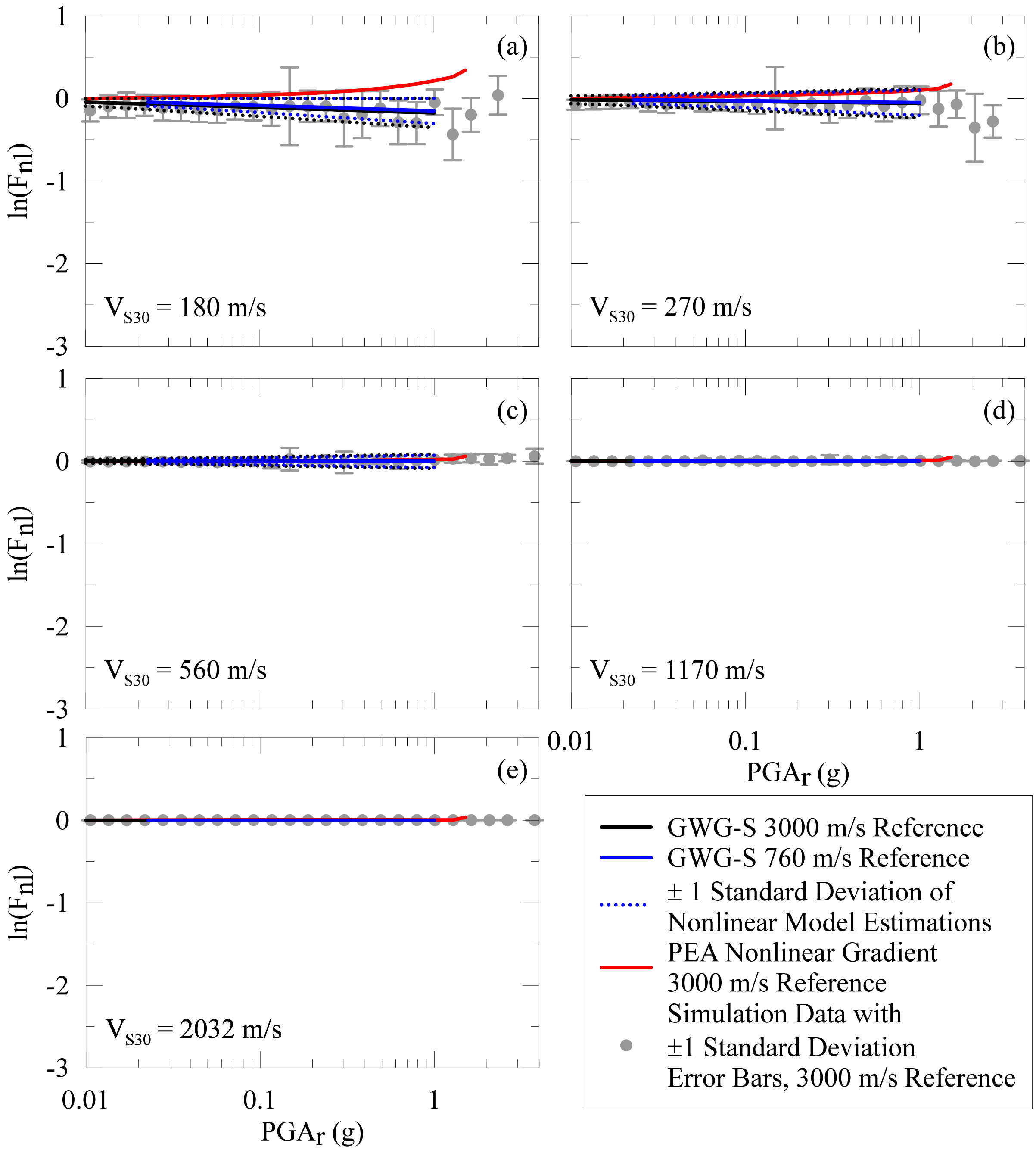

Figure 3.25 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1*σ*, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 4.0 sec.**

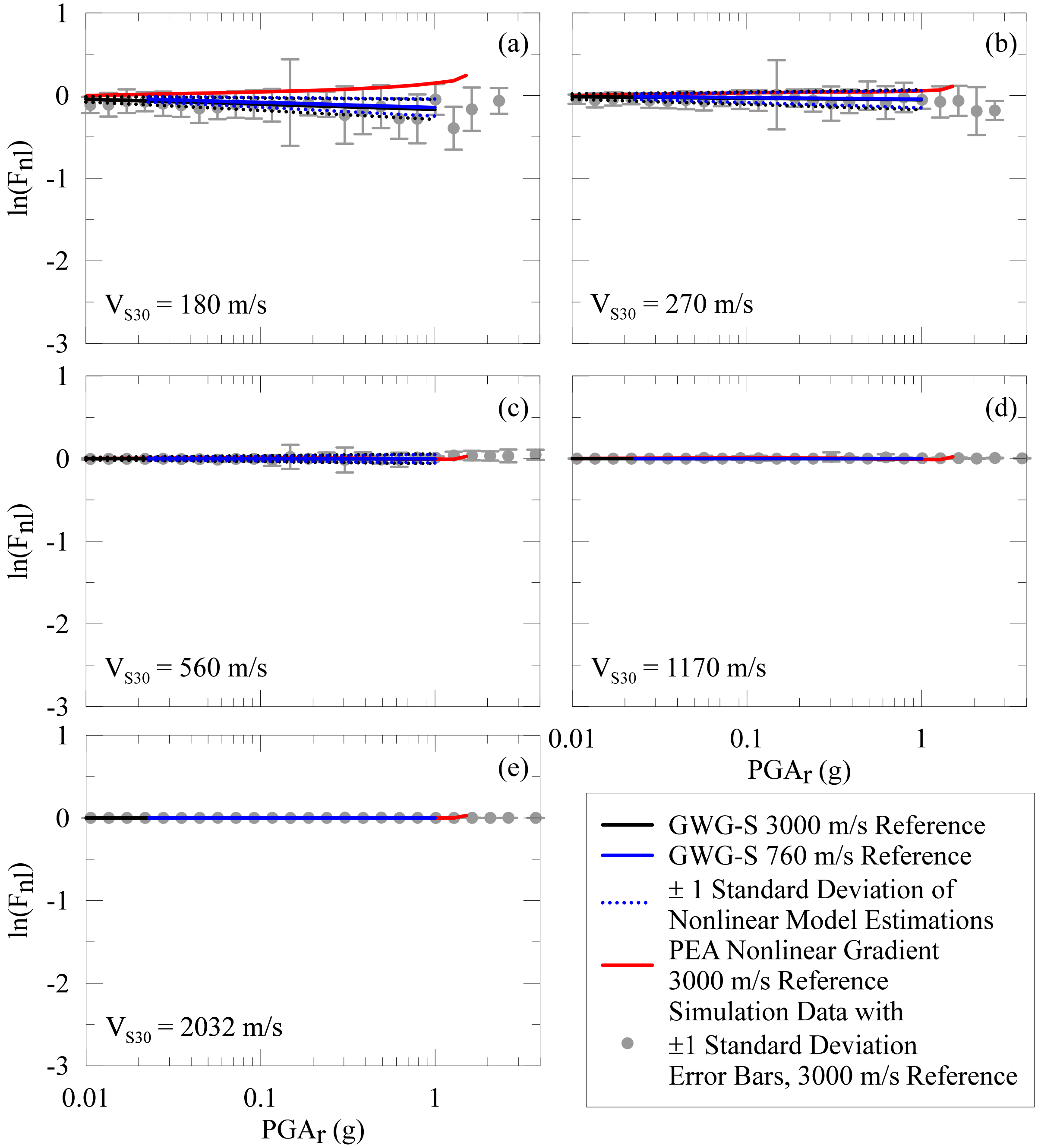

Figure 3.26 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/s, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 5.0 sec.**

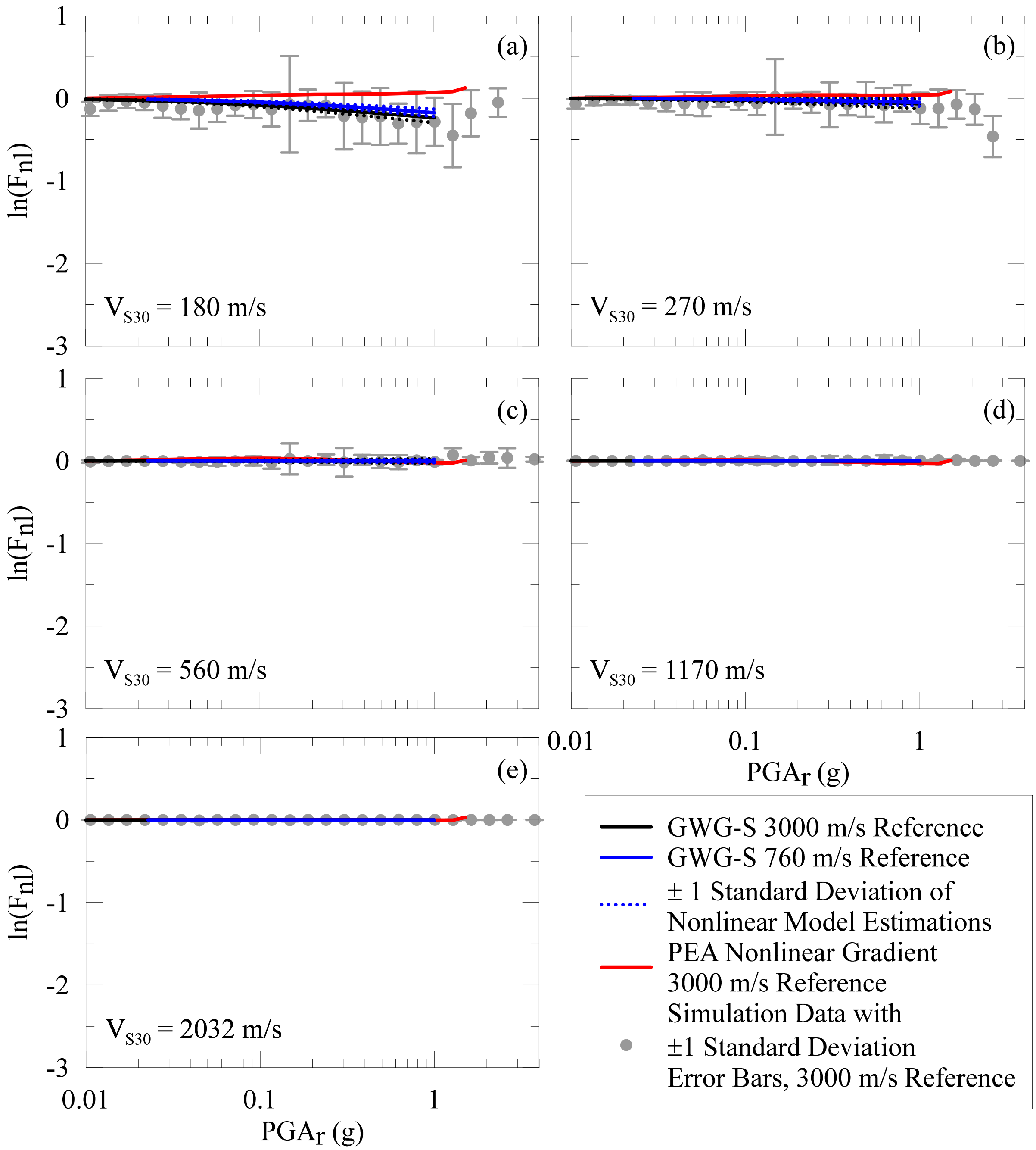

Figure 3.27 **Two recommended nonlinear amplification models relative to 3000 m/sec and 760 m/sec reference conditions with ± 1σ, PEA-Gradient nonlinear amplification model relative to 3000 m/sec, GWG nonlinear amplification data binned as function of V_{S30} and PGA for (a) V_{S30} = 180 m/sec, (b) V_{S30} = 270 m/sec, (c) V_{S30} = 560 m/sec, (d) V_{S30} = 1170 m/sec, and (e) V_{S30} = 2032 m/sec at an oscillator period of 10.0 sec.**

4 SUMMARY OF RECOMMENDED NONLINEAR AMPLIFICATION MODELS AND LIMITATIONS

In this report, two median nonlinear amplification models are recommended for capturing the site nonlinearity in central and eastern North America with an epistemic uncertainty model. The GWG-S nonlinear amplification model developed in Harmon [2017] is recommended for a reference condition of V_S = 3000 m/sec. For the use of this model with USGS hazard maps relative to 760 m/sec, the GWG-S nonlinear amplification model, in which input intensity measure (PGA_r) is converted to V_{S30} = 760 m/sec reference condition is recommended. A recommended epistemic uncertainty model on the median nonlinear amplification models is proposed to provide reasonable variation of nonlinear amplification in CENA.

4.1 RECOMMENDED MODEL FORM AND COEFFICIENTS

The functional form and coefficients for GWG-S recommended median nonlinear amplification model relative to 3000 m/sec reference condition are presented in Equations (2.2) and (2.3), and Table 2.1, respectively, and it is detailed in Section 3.2.1. The proposed nonlinear amplification model relative to 760 m/sec is explained in Section 3.2.2 with the methodology of converting 760 m/sec reference condition into 3000 m/sec. The epistemic uncertainty model form to represent the variation of on two recommended median nonlinear amplification model is detailed in Section 3.3.

4.2 RECOMMENDED MODEL LIMITATIONS

Recommended median nonlinear amplification limitations result from two sources as: limitations from 1D site response simulations and those from proposed models. Proposed amplification models are based on 1D site response simulations without multi-dimensional and basin effects, and 1D assumption of site response begins to break down for simulations that result in high shear strains within the soil profile during analysis.

Model limitations are limits on ground motion intensity (PGA$_r$), soil profile stiffness represented by V_{S30}, and the limit on shear strain index I_y = PGV/V_{S30} as given in Harmon [2017]. Recommended models are applicable for PGA$_r$ < 1.0g, and sites with V_{S30} greater than 200 m/sec, which is similar to the boundary of V_{S30} = 180 m/sec between NEHRP [BSSC 2015] site classes D and E. The shear strain index applicability of proposed models are reported as 0.1 % < I_y < 0.2 % in Harmon [2017]. For sites and ground motion conditions outside the range considered, a site-specific analysis is recommended.

For consistency with the recommended linear model in Stewart et al. [2017], the recommendations on the nonlinear amplification in this report have an additional maximum V_{S30} of applicability and period range limitations. The maximum limiting V_{S30} is 2000 m/sec, and the recommended period range is 0.08 sec to 5.0 sec. The GWG-S nonlinear amplification model is developed for a wider V_{S30} and period range, and the additional V_{S30} and period range constraints are applied for the purposes of this report.

5 CONCLUSIONS

This report details the expert panel recommendations for ergodic median nonlinear site amplification models for two reference conditions (V_S = 3000 m/sec and V_S = 760 m/sec) in CENA and an associated epistemic uncertainty model. The recommended median amplification models are the GWG-S amplification model for reference-rock condition of V_S = 3000 m/sec, and a modified GWG-S amplification model for reference-rock condition of V_S = 760 m/sec where a 760/3000 conversion on PGA_r is used. The recommended median models are compared to the Darragh et al. [2015] PEA model and found to be similar.

The recommended epistemic uncertainty on the median models is a judgement-based model that modifies the f_2 coefficients of the GWG-S models. The range of behavior on the f_2 coefficients, σ_{f2}, is a period dependent piecewise function of V_{S30}. The epistemic uncertainty is constant for V_{S30} < 300 m/sec. The log-linear relationship is assigned to σ_{f2} for 300 m/sec ≤ V_{S30} < 1000 m/sec, which converges to 0 for V_{S30} > 1000 m/sec. The epistemic uncertainty model on the median amplification models is compared to the binned mean and ±1 standard deviation of the nonlinear simulation amplification data from Harmon [2017] and found to produce a similar range of model behavior.

The nonlinear amplification models included in this report have certain limitations resulting from the assumptions of 1D site response calculations and model development. The median models in this report do not include the effects of deep-soil sites and basin effects. The recommended models are valid for rock outcrop PGA of up to 1.0g, for sites of V_{S30} < 200 m/sec, and combined site and ground motion conditions of I_y = PGV/V_{S30} less than the upper bound threshold of 0.1 % < I_y < 0.2 %.

REFERENCES

Al Noman, M.N., Cramer C.H. (2015). Empirical ground-motion prediction equations for Eastern North America *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 193–212.

Atkinson G.M., Boore D.M. (2006). Earthquake ground-motion prediction equations for eastern North America, *Bull. Seismol. Soc. Am*., 96(6): 2181–2205.

Boore D.M. (2015). Point-source stochastic-method simulations of ground motions for the PEER NGA-East project, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 11–49.

BSSC (2015). NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (FEMA P-1050-1), Building Seismic Safety Commission, National Institute of Building Sciences, Washington, D.C.

Campbell K.W. (2003). Prediction of strong ground motion using the hybrid empirical method and its use in the development of ground-motion (attenuation) relations in eastern North America, *Bull. Seismol. Soc. Am*., 93(3): 1012–1033.

Chiou B.S.J., Youngs R.R. (2008). NGA model for average horizontal component of peak ground motion and response spectra, *PEER Report No. 2008/09*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA,

Darragh R.B., Abrahamson N., Silva W.J., Gregor N. (2015). Development of hard rock ground-motion models for Region 2 of Central and Eastern North America, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 51–69.

Frankel A.D. (2015). Ground-motion predictions for Eastern North American earthquakes using hybrid broadband seismograms from finite-fault simulations with constant stress-drop scaling, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 149–163.

Frankel A.D., Mueller C.S., Perkins D., Barnhard T., Leyendecker E., Safak E., Hanson S., Dickman N., Hopper M. (1996). *National Seismic Hazard Maps*, Documentation June 1996, U.S. Geological Survey: 69 pgs.

Goulet C.A., Kishida T., Ancheta T.D., Cramer C.H., Darragh R.B., Silva W.J., Hashash Y.M.A., Harmon J.A., Stewart J.P., Wooddell K.E., Youngs R.R. (2014). PEER NGA-East Database, *PEER Report No. 2014/17*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

Graizer V. (2015). Ground-Motion Prediction Equations for the Centeral and Eastern United States, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 51–69.

Harmon J.A. (2017). *Nonlinear Site Amplification Functions for Central and Eastern North America*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of Illinois at Urbana Champaign, Urbana, IL.

Hashash Y.M.A., Kottke A.R., Stewart J.P., Campbell K.W., Kim B., Moss C., Nikolaou S., Rathje E.M., Silva W.J. (2014). Reference rock site condition for Central and Eastern North America, *Bull. Seismol. Soc. Am.,* 104(2): 684–701.

Hassani B., Atkinson G.M. (2015). Reference empirical ground-motion model for Eastern North America, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 251–272.

Hollenback J., Kuehn N., Goulet C.A., Abrahamson N.A. (2015). PEER NGA-East median ground-motion models, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 274–309.

Kamai R., Abrahamson N.A., Silva W.J. (2014). Nonlinear horizontal site amplification for constraining the NGA-West2 GMPEs, *Earthq. Spectra*, 30(3): 1223–1240.

Parker et al. (2017). NGA-East GWG Empirical Linear Amplification Model Report (Under Development).

Petersen M.D., Frankel A.D., Harmsen S.C., Mueller C.S., Haller K.M., Wheeler R.L., Wesson R.L., Zeng Y., Boyd O.S., Perkins D.M., Luco N., Field E.H., Wills C.J., Rukstales K.S. (2008). Documentation for the 2008 Update of the United States National Seismic Hazard Maps, *Open-File Rept. 2008-1128*, U.S. Geological Survey, Menlo Park, CA.

Petersen M.D., Moschetti P., Powers M., Mueller C.S., Haller K.M., Frankel A.D., Zen Y., Rezaeian S., Harmsen S.C., Boyd O.S., Field E.H., Chen R., Rukstales K.S., Luco N., Wheeler R.L., Williams R.A., Olsen A.H. (2014). Documentation for the 2014 Update of the United States National Seismic Hazard Maps, *Open-File Rept. 2014-1091*, U.S. Geological Survey, Menlo Park, CA.

Pezeshk S., Zandieh A., Campbell K.W., Tavakoli B. (2015). Ground-Motion Prediction Equations for CENA Using the Hybrid Empirical Method in Conjunction with NGA-West2 Empirical ground-motion models, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 119–147.

Pezeshk S., Zandieh A., Tavakoli B. (2011). Hybrid empirical ground-motion prediction equations for Eastern North America using NGA models and updated seismological parameters, *Bull. Seismol. Soc. Am.,* 101(4): 1859–1870.

Seyhan E., Stewart J.P. (2014). Semi-empirical nonlinear site amplification from NGA-West2 data and simulations, *Earthq. Spectra*, 30(3): 1241–1256.

Shahjouei A., Pezeshk S. (2015). Hybrid empirical ground-motion model for Central and Eastern North America using hybrid broadband simulations and NGA-West2 GMPEs, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 165–192.

Silva W.J., Abrahamson N.A., Toro G., Costantino C. (1997). Description and validation of the stochastic ground motion model*, Contract No. 770573*, *Report submitted to Brook to Brookhaven National Laboratory*, Associated Universities, Inc. Upton, NY.

Silva W.J., Gregor N., Darragh R.B. (2002). *Development of Hard Rock Attenuation Relations for Central and Eastern North America*, internal report from Pacific Engineering, El Cerrito, CA.

Somerville P.G., Collins N., Abrahamson N.A., Graves R., Saikia C. (2001). Ground motion attenuation relations for the central and eastern United States, *Final Report to U.S. Geological Survey*, June 30, 2001, URS Group, Inc., Pasadena CA.

Stewart, J.P., Atkinson G.M., Boore D.M., Darragh R.B., Goulet C.A., Hashash Y.M.A., Silva W.J., Parker G.A., Harmon J.A. (2017). Expert panel-recommendations for ergodic site amplification in Central and Eastern North America, *PEER Report No. 2017/03*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

Tavakoli B., Pezeshk S. (2005). Empirical-stochastic ground-motion prediction for eastern North America, *Bull. Seismol. Soc. Am.,* 95(6): 2283–2296.

Toro G.R., Abrahamson N.A., Schneider J.F. (1997). Model of strong ground motions from earthquakes in Central and Eastern North America: Best estimates and uncertainties, *Seismol. Res. Lett.,* 68(1): 41–57.

Walling M., Silva W.J., Abrahamson N.A. (2008). Nonlinear site amplification factors for constraining the NGA models, *Earthq. Spectra*, 24(1): 243–255.

Yenier E., Atkinson G.M. (2015). Regionally-adjustable generic ground-motion prediction equation based on equivalent point-source simulations: Application to Central and Eastern North America, *PEER Report No. 2015/04*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA, pp. 85–118.

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