Practical Applications of Non-Ergodic Site Response

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Abstract

Ground-motion models (GMMs) are generally based on the ergodic assumption wherein global averages and aleatory variability from global datasets are assumed to be applicable at a site of interest. In reality, there are generally systematic differences between the GMM predictions and observed ground motions at a site of interest. To overcome this issue, non-ergodic (NE) methodologies have become more common in geotechnical practice. Non-ergodic approaches involve refinement of one or more of the terms in the GMM (i.e., source, path, and site) and allow for the use of a lower aleatory variability. This poster focuses on practical applications of non-ergodic methodologies. There is a focus on refinement of the GMM site term, which is the most commonly refined GMM term in practice. The poster presents a case history that illustrates similar trends, wherein the ergodic models underestimate spectral accelerations at the fundamental site period and overestimate spectral accelerations over other broad period ranges.

Data and Methodology

NE site response analysis involves replacing the ergodic site model (F_S) in the GMMs with a non-ergodic model. The non-ergodic F_S can be based on both a residuals analysis of local ground-motion recordings and/or simulations, which typically comprise one-dimensional ground-response analyses (GRA) (Stewart et al., 2017). The functional form of F_S is shown in the equation below.

$$F_S = Flin + Fnl = f_1 + f_2 ln(\frac{X_{1Mr} + f_3}{f_3})$$

In some situations, ground-motion (GM) recordings located at or near a site of interest can be used to develop a NE f_1 value, but typically the GM data do not extend to sufficiently high intensities to develop NE f_2 and f_3 values. GRAs can be performed to obtain all three terms, provided that the associated epistemic uncertainties are considered. For the case studies discussed herein, we used local GM records to estimate f_1 and GRA to estimate f_1 and f_2 (Stewart et al., 2017). In addition to replacing the ergodic F_S with a NE F_S, the approach described herein involves modifying the GMM standard deviation(s).

Google Landings Case Study

Shear-Wave Velocity and Site Period:

In Figures 1a and 1b, we present V_S profiles that we developed through a joint inversion of surface-wave and horizontal-to-vertical spectral ratio (HVSR) data. We performed multiple inversions using the "layering ratio" approach (Cox and Teague, 2016) and developed a suite of profiles that reasonably capture this uncertainty.

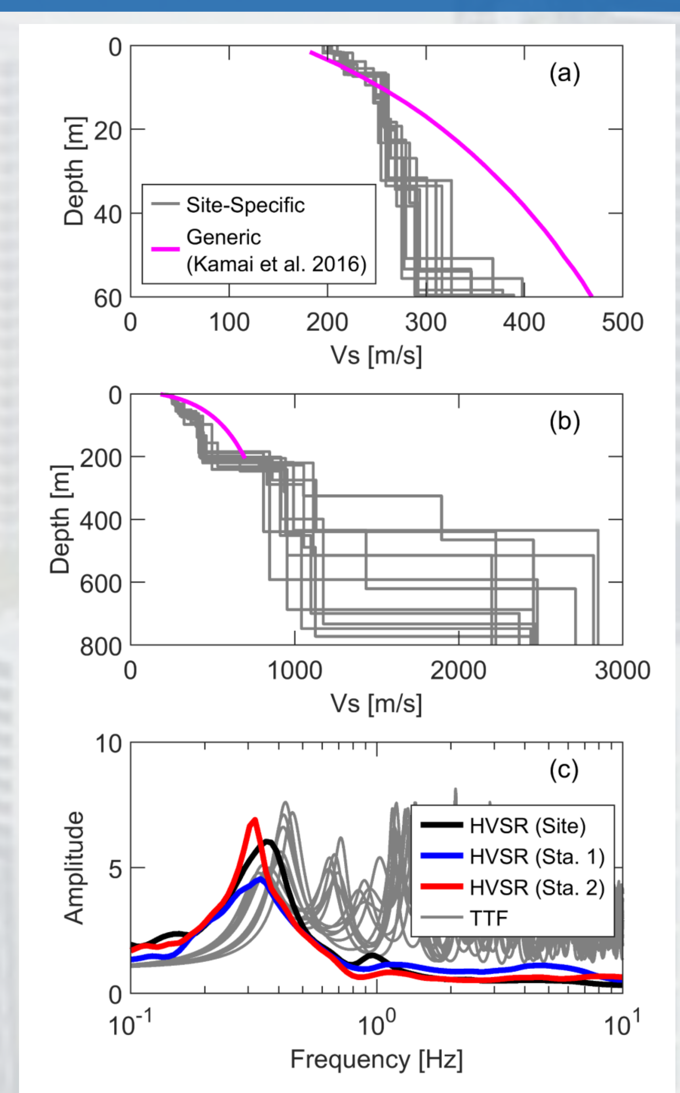


Fig. 1. V_S profiles from surface-wave testing at the Landings Campus, shown to maximum depths of (a) 60 and (b) 800 meters, along with the generic V_{S30} based profile from Kamai et al. (2016). In (c), the HVSR data from the project site and nearby ground-motion recording stations are compared along with the theoretical transfer functions for the V_S profiles.

Residual Analysis

In Figure 2, we present the within-event residuals computed for two GM recording stations based on the BSSA GMM. A positive residual indicates that the GMM tends to underestimate SA(T) and vice versa.

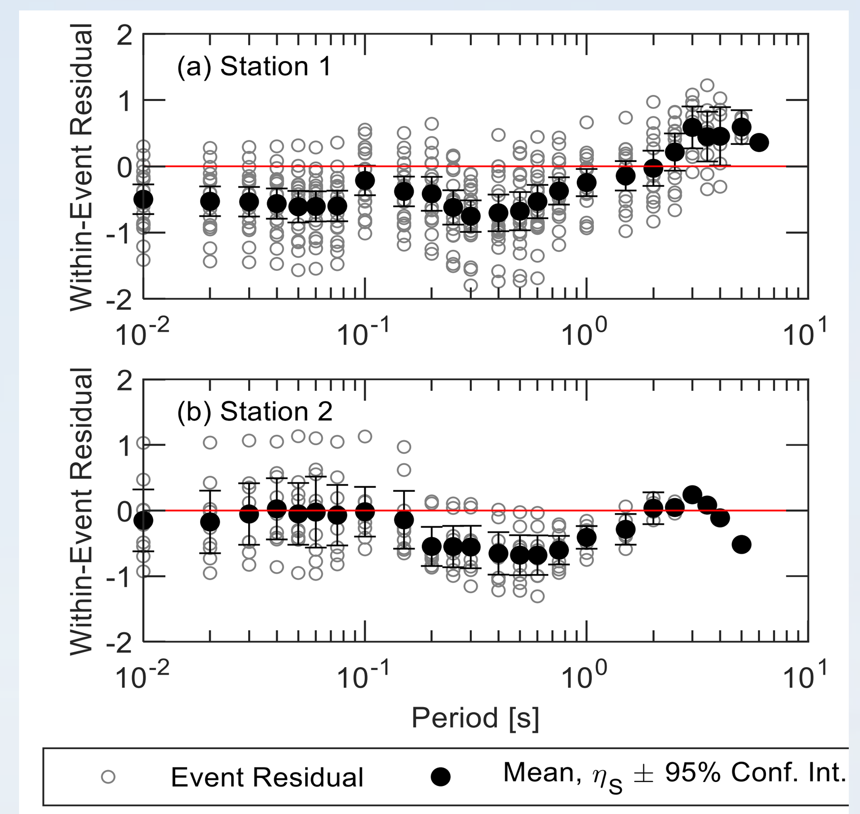


Fig. 2. Within-event residuals from (a) Station 1 and (b) Station 2 near the Google Landings Campus.

Amplification Function

We estimated NE f_1 values based on both the residuals described previously and linear GRAs that we performed using the site V_S profiles. We estimated NE f_2 values based on nonlinear GRAs performed using a suite of over 100 input ground motions.

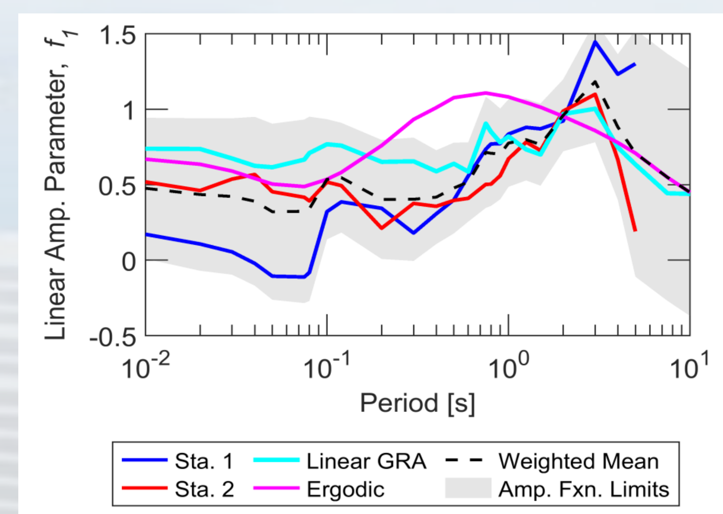


Fig. 3. Period-dependent linear amplification parameters for the Google Landings campus.

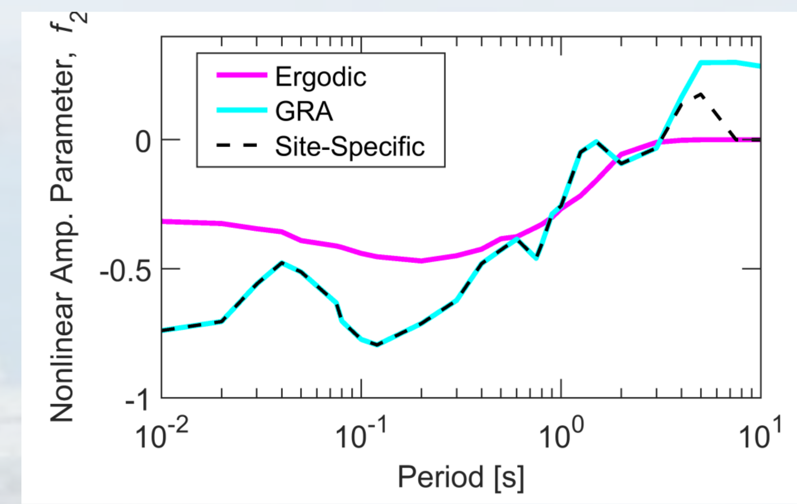
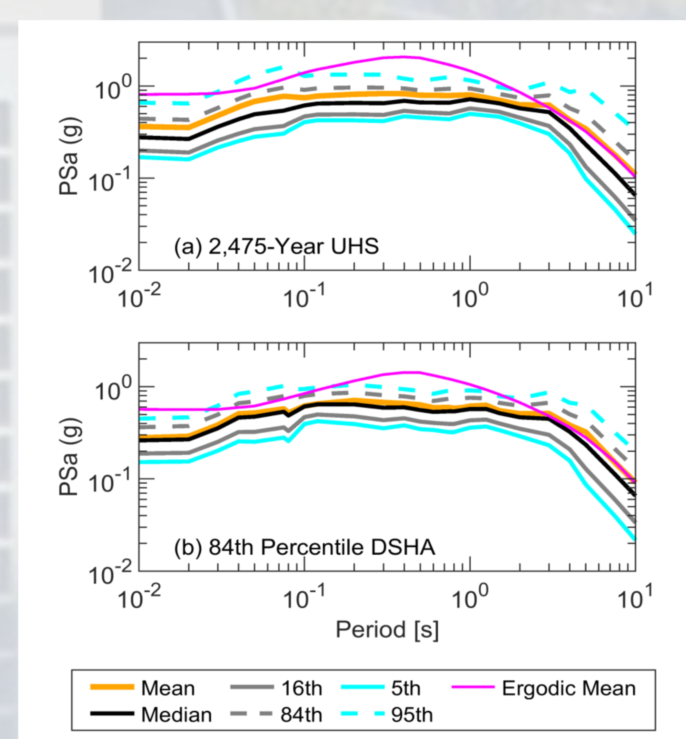


Fig. 4. Period-dependent nonlinear amplification parameters for the Google Landings Campus.

Results and Conclusions

- The NE mean is significantly lower than the ergodic mean at periods less than approximately 2.5 sec
- The NE SHA results yielded significant reductions in the seismic demands on the structure, leading to a more efficient structural design.



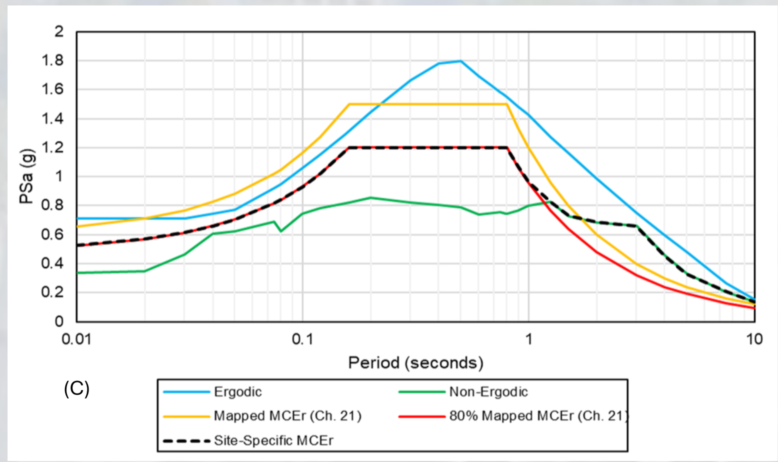


Fig. 5. Non-ergodic (a) 2,475-year mean uniform hazard response spectra, (b) 84th percentile deterministic response spectra for the Google Landings site, and (c) Final spectrum

Select Non-Ergodic SHA Projects

Atlas Block, San Francisco, CA

555 Bryant Street, San Francisco, CA

Brooklyn Basin, Oakland, CA

300 Lakeside, Oakland , CA

Treasure Island Block C2, San Francisco, CA

Google Landings, Mountain View, CA

Google Caribbean, Sunnyvale, CA

Meta Campus, Menlo Park, CA

Bo Town, San Jose, CA

Lucas Museum of Narrative Art, Los Angeles, CA

300 Lakeside. Oakland, CA

Lucas Museum of Narrative Art

Google Landings