ADVANCEMENT OF HAZARD-CONSISTENT GROUND MOTION SELECTION: REFINEMENTS TO CONDITIONAL MEAN SPECTRUM CALCULATIONS

PEER Transportation Systems Research Program

Principal Investigator: Jack W. Baker, Stanford University

Student Investigator: Ting Lin, Stanford University

The John A. Blume Earthquake Engineering Center, Stanford University

Introduction

Ground motion selection is often associated with a target response spectrum.

The Conditional Mean Spectrum (CMS) links seismic hazard information with ground motion selection for dynamic structural analysis.

As this CMS concept is considered for practical use, several common approximations need to be further explored.

Refinements to the CMS calculations can incorporate aleatory uncertainties from causal magnitudes (*M*) and distances (*R*), as well as epistemic uncertainties from ground motion prediction models (GMPMs).

This work is possible in part due to new deaggregation features in the 2008 US Geological Survey Hazard Mapping tools.

Basic CMS computation

Obtain a target spectral acceleration at period T_1, $Sa(T_1)^*$, from probabilistic seismic hazard analysis (PSHA), and the associated *M* and *R* from deaggregation.

Compute the mean and standard deviation of logarithmic *Sa* at all periods of interest (T_i) for the target *M*, *R* and other associated parameters (θ), using a GMPM. We denote these

$$\mu_{lnSa}(M,R,\theta,T_i) \qquad \sigma_{lnSa}(M,\theta,T_i)$$

For the target *Sa*, compute ε at T_1:

$$\varepsilon(T_1) = \frac{lnSa(T_1)^* - \mu_{lnSa}(M,R,\theta,T_1)}{\sigma_{lnSa}(M,\theta,T_1)}$$

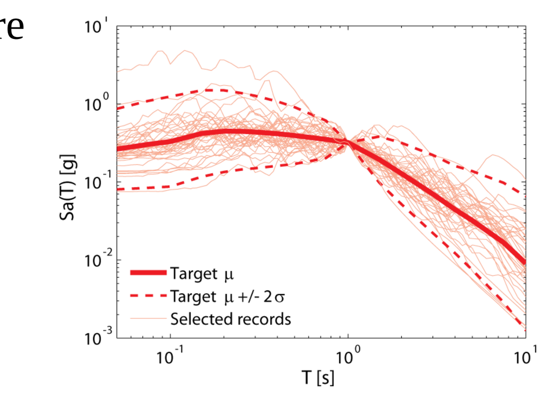
Find the conditional mean and standard deviation ln*Sa* at all T_i:

$$\mu_{lnSa}(T_i)^* = \mu_{lnSa}(M,R,\theta,T_i) + \rho(T_1,T_i)\varepsilon(T_1)\sigma_{lnSa}(M,\theta,T_i)$$

$$\sigma_{lnSa}(T_i)^* = \sigma_{lnSa}(M,\theta,T_i)\sqrt{1-\rho(T_1,T_i)^2}$$

Which M, R and GMPM to use?

This CMS can be used as a target for ground motion selection, by selecting and scaling ground motions so that their spectra match this target, as illustrated here



Using this approach at real sites requires us to consider:

- Deaggregation will produce multiple causal magnitude and distance values for a given $Sa(T_1)$ amplitude
- Real PSHA calculations use multiple ground motion prediction models (GMPMs)

Correct implementation of the CMS requires us to incorporate these multiple *M* and *R* values and multiple GMPMs, using the following approximate or exact calculation methods.

Approximate CMS (logic-tree weights)

Compute the approximate CMS using the mean *M* and *R* from deaggregation (**$\bar{M}$, $\bar{R}$**) and GMPM *k*:

$$\mu_{lnSa,k}(T_i)^{*\prime} \approx \mu_{lnSa,k}(\bar{M},\bar{R},\bar{\theta},T_i) + \rho(T_i,T^*)\sigma_{lnSa,k}(\bar{M},\bar{\theta},T_i)\bar{\varepsilon}(T^*)$$

$$\sigma_{lnSa,k}(T_i)^{*\prime} \approx \sigma_{lnSa,k}(\bar{M},\bar{\theta},T_i)\sqrt{1-\rho(T_1,T_i)^2}$$

Compute the composite CMS with multiple GMPMs using GMPM logic-tree weights, p_k':

$$\mu_{lnSa}(T_i)^{*\prime} \approx \sum_k p_k' \mu_{lnSa,k}(T_i)^{*\prime}$$

$$\sigma_{lnSa}(T_i)^{*\prime} \approx \sqrt{\sum_k p_k'(\sigma_{lnSa,k}(T_i)^{*2\prime} + (\mu_{lnSa,k}(T_i)^{*\prime} - \mu_{lnSa}(T_i)^{*\prime})^2)}$$

Approximate CMS (deagg weights)

Compute the CMS using the mean *M* and *R* from GMPM-specific deaggregation ($\bar{M}_k$, $\bar{R}_k$) and GMPM *k*:

$$\mu_{lnSa,k}(T_i)^* \approx \mu_{lnSa,k}(\bar{M}_k,\bar{R}_k,\bar{\theta}_k,T_i) + \rho(T_i,T^*)\sigma_{lnSa,k}(\bar{M}_k,\bar{\theta}_k,T_i)\bar{\varepsilon}_k(T^*)$$

$$\sigma_{lnSa,k}(T_i)^* \approx \sigma_{lnSa,k}(\bar{M}_k,\bar{\theta}_k,T_i)\sqrt{1-\rho(T_1,T_i)^2}$$

Compute the composite CMS with multiple GMPMs using GMPM deaggregation weights, p_k:

$$\mu_{lnSa}(T_i)^* = \sum_k p_k \mu_{lnSa,k}(T_i)^*$$

$$\sigma_{lnSa}(T_i)^* = \sqrt{\sum_k p_k(\sigma_{lnSa,k}(T_i)^{*2} + (\mu_{lnSa,k}(T_i)^* - \mu_{lnSa}(T_i)^*)^2)}$$

Exact CMS

Compute the CMS using each individual *M* and *R* from hazard deaggregation (M_j, R_j) and GMPM *k*:

$$\mu_{lnSa,j,k}(T_i)^* = \mu_{lnSa,k}(M_j,R_j,\theta_j,T_i) + \rho(T_1,T_i)\varepsilon_j(T_1)\sigma_{lnSa,k}(M_j,\theta_j,T_i)$$

$$\sigma_{lnSa,j,k}(T_i)^* = \sigma_{lnSa,k}(M_j,\theta_j,T_i)\sqrt{1-\rho(T_1,T_i)^2}$$

Compute the composite CMS with multiple GMPMs using individual deaggregation weights, $p_{j,k}$:

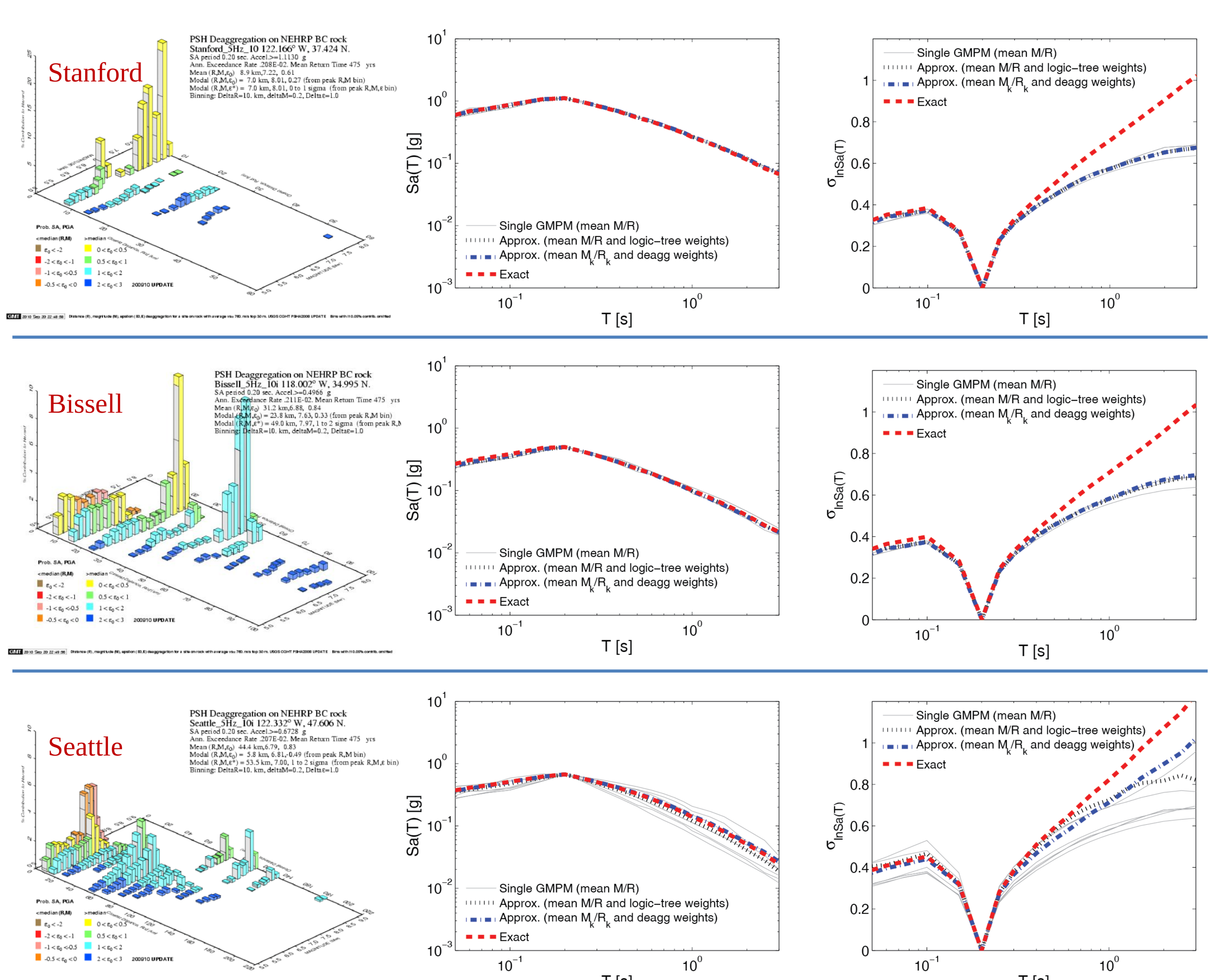
$$\mu_{lnSa}(T_i)^* = \sum_k \sum_j p_{j,k} \mu_{lnSa,j,k}(T_i)^*$$

$$\sigma_{lnSa}(T_i)^* = \sqrt{\sum_k \sum_j p_{j,k}(\sigma_{lnSa,j,k}(T_i)^{*2} + (\mu_{lnSa,j,k}(T_i)^* - \mu_{lnSa}(T_i)^*)^2)}$$

Example calculations

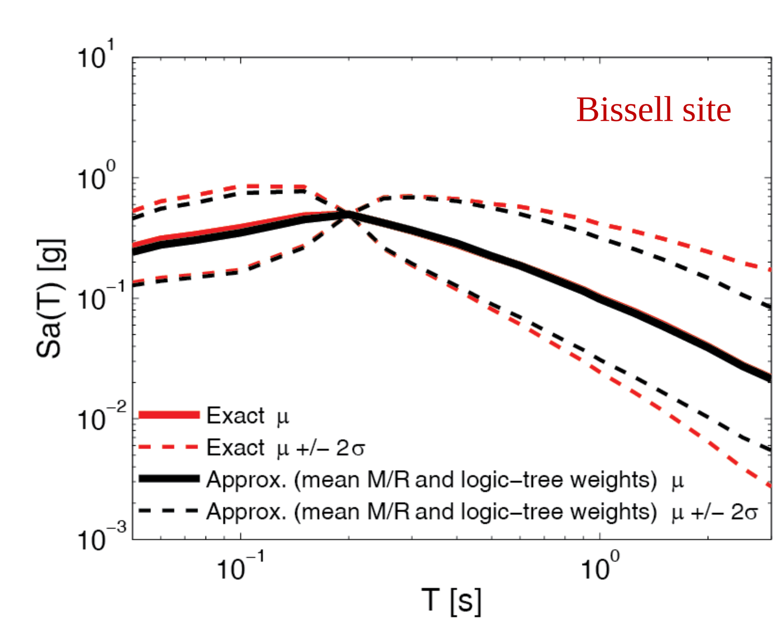
Conditional Spectra for three locations are computed using the methods described above, to evaluate the accuracy of the approximate methods.

Site	Location	# Main sources	Source type	# GMPMs
Stanford	Northern California	Single	Crustal	3
Bissell	Southern California	Multiple	Crustal	3
Seattle	Pacific Northwest	Multiple	Crustal, interface, intraplate	7



Ground motion selection

To investigate the effect of approximations on ground motion selection, target spectra using exact and approximate CMS can be compared.



Our tool to select ground motions that match a target spectrum mean and variance is documented and publicly available at: http://stanford.edu/~bakerjw/gm_selection.html

Structural analyses are currently being carried out to determine whether there is a practical difference in structural response resulting from the use of the above exact or approximate target.

Discussion and Conclusions

Several exact and approximate implementations of Conditional Mean Spectrum computations are presented and used for example calculations.

Exact CMS mean and standard deviation calculations can incorporate multiple GMPMs and *M*/*R* combinations.

Approximate CMS calculations appear to be more accurate for mean estimation than for standard deviation estimation.

The approximation of using a single GMPM works best for sites with a single source, followed by multiple sources of the same type, and then multiple source types.

Exact methods may be needed for locations with hazard contributions from multiple sources with different source types, where errors from approximations are higher.

Extension of PSHA deaggregation to deaggregation of GMPMs and other parameters provided essential information for refinements to the CMS calculations.

These refined CMS computations facilitate hazard-consistent ground motion selection for dynamic structural analysis.

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