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. 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.

### Approximate CMS (logic-tree weights)

Compute the approximate CMS using the mean M and R from deaggregation (M, R) and GMPM k:

$$\mu_{\text{approx}}(T) = \mu_{\text{approx}}(M, R, \theta, T) + p(T) \sigma_{\text{approx}}(M, R, \theta, T) T^2$$

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

$$\mu_{\text{approx}}(T) = \sum_k p_k \mu_{\text{approx}}(T)|^{k}$$

$$\sigma_{\text{approx}}(T) = \sqrt{\sum_k p_k (\sigma_{\text{approx}}(T)|^{k} - \mu_{\text{approx}}(T)|^{k})^2}$$

### Approximate CMS (deag weights)

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

$$\mu_{\text{approx}}(T) = \mu_{\text{approx}}(M, R, \theta, T) + p(T) \sigma_{\text{approx}}(M, R, \theta, T) T^2$$

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

$$\mu_{\text{approx}}(T) = \sum_k p_k \mu_{\text{approx}}(T)|^{k}$$

$$\sigma_{\text{approx}}(T) = \sqrt{\sum_k p_k (\sigma_{\text{approx}}(T)|^{k} - \mu_{\text{approx}}(T)|^{k})^2}$$

### Exact CMS

Compute the CMS using each individual M and R from hazard deaggregation ($\mathbf{M}_j, \mathbf{R}_j$) and GMPM k:

$$\mu_{\text{exact}}(T) = \mu_{\text{exact}}(M, R, \theta, T) + p(T) \sigma_{\text{exact}}(M, R, \theta, T) T^2$$

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

$$\mu_{\text{exact}}(T) = \sum_k p_k \mu_{\text{exact}}(T)|^{k}$$

$$\sigma_{\text{exact}}(T) = \sqrt{\sum_k p_k (\sigma_{\text{exact}}(T)|^{k} - \mu_{\text{exact}}(T)|^{k})^2}$$

### Example calculations

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

### Discussion and Conclusions

Several exact and approximate implementations of Conditional Mean Spectrum calculations 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.