GEM - PEER Global Ground Motion Prediction Equations Project: An Overview

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ABSTRACT:
The Global Earthquake Model (GEM) Foundation is an international organization with various global and regional components to carry out global risk analysis. One of GEM's global components is global Ground Motion Prediction Equations (GMPEs) project, which is a multi-disciplinary and multi-institutional program being coordinated by the Pacific Earthquake Engineering research Center (PEER). Building on the most recent advances in the field, PEER has gathered a distinguished international team of 27 experts who are using a unified, transparent and collaborative approach to select a harmonized suite of GMPEs that can be used at the global and possibly regional levels for seismic hazard calculations. The project consists of seven working groups, with active technical interactions. Based on a systematic and consistent set of evaluation criteria, existing GMPEs for major tectonic environments have been screened and selected by the working groups. This paper provides an overview of the GEM – PEER Global GMPEs project. The framework of the project and scopes of the working groups are summarized in this paper.

Keywords: ground motion prediction equations, GMPE, attenuation relations, Global Earthquake Model, GEM seismic hazard

1. INTRODUCTION

Ground Motion Prediction Equations (GMPEs), or "attenuation" relationships, are efficiently used to estimate ground motions for use in both deterministic and probabilistic seismic hazard analyses. The results of such hazard analyses are used for a wide range of applications such as: (1) site-specific seismic analysis and design of facilities; (2) development of regional seismic hazard maps for use in building codes, financial estimation, etc.; and (3) social and financial loss estimation.

The Global Ground Motion Prediction Equations (GMPEs) project is part of an international research initiative supported by the Global Earthquake Model (GEM) Foundation, and was undertaken to select and recommend a small set of harmonized suite of GMPEs that can be used at the global and possibly regional levels for GEM seismic hazard calculations and associated loss estimation studies.

The project is coordinated by the Pacific Earthquake Engineering Research Center (PEER). PEER's team consists of a distinguished international panel of experts to use a unified, transparent and collaborative approach by building on the most recent advances in the field. The project has been accomplished through a research program which has implemented a comprehensive evaluation of the scaling of ground shaking by fostering high level interaction among different aspects of GMPEs, organized in different task.

An overview of the GEM – PEER Global GMPEs project components, and process is presented in this paper. Other companion papers included in the Proceeding of this conference present more details of several tasks.

2. PROJECT PLAN

The project kick-off meeting with the entire members of the GEM – PEER Global GMPEs project was held on February 2011 via Internet. The purpose of the meeting was to:

- Review the GEM – Global GMPEs project plan,
- Set deadlines and milestone for each working group (WG), and
- Agree upon tasks and deliverables expected from each WG.

In the weeks following the kick-off meeting, the working groups had their own individual kick-off meetings, finalized the working groups' memberships, formulated their research plans, set detailed deadlines and deliverables, and initiated the research.

2.1. Project organization

Organization leadership for the GEM Global GMPEs project is provided by the Pacific Earthquake Engineering Research Center (PEER). Technical coordination of the project has been carried out by a "Coordination Committee" (the second to fifth co-authors of this paper). The project Coordination Committee interacted regularly with the project's participants to communicate interim findings and ensure that the project's goals are achieved.

The project is carried out by a distinguished panel of 27 international experts from various parts of the world. Combined, they have extensive GMPE expertise worldwide. They participants were grouped into different working groups (WGs) for each of the tasks listed in Table 1. The key role of the WGs was to review and provide a consensus based, best practice, set of recommendations specific to each topic assigned to WG. The members of the WGs interacted regularly via web-conference application, through e-mail exchange, and by using collaborative platforms hosted by PEER.

Table 1. List of tasks in GEM – PEER Global GMPEs project

Task Number	Task Title
1.a	Defining a consistent strategy for modelling ground motions
1.b	Estimating site effects in parametric ground motion models
2	Compile and Critically Review GMPEs
3	Select a Global Set of GMPEs
4	Include Near-Fault Effects
5	Build an Inventory of Recorded Waveform Databases
6	Design the Specifications to Compile a Global Database of Soil Classification

Upon achieving agreement within each WG, the recommended approaches or models were distributed to the broader project community to collect their feedback, prior being finalized. For this purpose, an intensive two-day workshop has been organized in Istanbul, Turkey, in mid-May 2012. The face-to-face interaction and plenary participation of the project members are the key elements to ensure global consensus and harmonization of the recommendations.

3. MAIN TECHNICAL ISSUES ADDRESSED IN THE PROJECT

This section presents the key tasks of the project, their scope, and the principal findings discussed among the individual WGs. The project will be completed in late 2012 and details of Tasks 1 through 6 will be documented in a final PEER report.

3.1. Task 1: Define a Consistent Strategy to Model Ground Motion

This task aims at identifying consistent protocols for selection of input parameters required for ground motion estimation and also identify approaches for ground motion estimation. The Task's recommendations can be used efficiently for reliable deterministic and probabilistic seismic hazard analyses (PSHA). The task is subdivided into two components: Task 1a, defining a consistent strategy for modeling ground motions, and Task 1b, estimating site effects in parametric ground motion models.

3.1.1. Task 1a: Define a Consistent Strategy to Model Ground Motion

In this task, critical aspects of seismological predictor parameters used by predictive model developers to estimate ground motions for different earthquake scenarios are investigated. The key parameters include seismic source parameters (magnitude and style-of-faulting), source-to-site distance, and local site conditions. Potential significance of each predictor parameter used in functional forms of GMPEs has been identified.

Some GMPEs include additional parameters beyond the standard parameters of magnitude and distance. Task 1a involved a review of the following additional predictive parameters:, orientation and propagation of the fault rupture, Z_{TOR} (depth to top-of-rupture), basin effects modeled in terms of $Z_{1.0}$ and $Z_{2.5}$ (depth from the ground surface at which shear-wave velocity attains values of 1.0 km/s and 2.5 km/s, respectively), hanging-wall effects, nonlinear site effects, V_{s30} (average shear-wave velocity in the upper 30 m of the soil profile), and kappa (high-frequency filter considered to be related to near-surface attenuation). Task 1a also involved a review of the description of the ground motion parameters to be used including the definition of the horizontal component of shaking the dispersion around the median estimate (in term of standard deviation associated with the GMPEs) and its partition in aleatory and epistemic variability associated with ground motion. Additionally, various approaches used to derive GMPEs in case of absence or paucity of the required predictive parameters were discussed.

The outcome of Task 1a has been a set of recommendations for the optimum performance of each major predictor parameter. Those recommendations highlight the required features of these parameters as well as the predictive models that are believed lead to a consistent seismic hazard assessment. For this purpose, particular effort has been made to analyze available literature, review approaches used in previous PSHA studies, and discuss options for best practice useful for GEM Hazard Platform implementation (open-source software OpenQuake to compute seismic hazard and risk, available at http://openquake.org). Further details on this task can be found in the companion paper by Akkar et al. (2012).

3.1.2. Task 1b: Estimating site effects in parametric ground motion models

In this task, the WG reviewed site parameters used in GMPEs for various tectonic regimes and described procedures for estimation of site parameters in the absence of site-specific data. Since most modern GMPEs characterized the site by the average shear wave velocity in the upper 30 m of the site (V_{s30}) either directly or as the basis for site classification into categories, the WG recommended that, for site-specific applications, V_{s30} should be obtained from on-site geophysical measurements. When those measurements extend to a depth $Z_p < 30$ m, V_{s30} can be estimated using various extrapolation methods. In the absence of on-site geophysical data, or for regional ground motion studies, estimation of V_{s30} from geological or topographic data will generally be required. Geology- and terrain-based correlations are available that are calibrated against California data. Ground slope correlations are available that utilize additional data sources from specific regions world-wide.

More details of Task 1b can be found in a companion paper by Stewart et al. (2012a).

3.2. Task 2: Compile and Critically Review GMPEs

In this task, candidate GMPEs were identified, compiled, and reviewed for four tectonic categories of earthquakes: (a) shallow crustal earthquakes in active tectonic regions, (b) shallow crustal earthquakes in stable continental (possibly divided further into shield and continental/foreland) regions, (c) subduction zone interface earthquakes, and (d) subduction zone intraslab (Wadati-Benioff) earthquakes. Additionally, volcanic zones, deep non-focus subduction zones (i.e. where slab delamination and detachment phenomena are present and deep earthquakes have or could occur), and zones with travel paths along oceanic crust are considered.

The companion paper by Cotton et al. (2012) illustrates the selection process used by the WG to preselect the most recent and robust GMPEs using criteria consistent with the current state-of-the-art ground-motion characterization. The WG identified an ensemble of about thirty GMPEs. A subset of models will be selected that capture the epistemic uncertainty in the prediction of shaking.

For the pre-selection, the WG decided to apply the seven criteria proposed by Cotton et al. (2006):

1. the model is from a clearly irrelevant tectonic regime;
2. the model is not published in an international peer-reviewed journal;
3. the documentation of model and its underlying dataset is insufficient;
4. the model has been superseded by more recent publications;
5. the frequency range of the model is not appropriate for engineering application;
6. the model has an inappropriate functional form;
7. the regression method or regression coefficients are judged to be inappropriate.

Furthermore, the selected models were required to be consistent with the outcome of Task 1a (Akkar et al., 2012) which describes and suggests predictive parameters to use for ground-motion modelling and their proper ranges. The list of preselected models for the main seismo-tectonic regimes is shown in Table 2.

Attributes and details on the listed models are available at a dedicated report (PEER GEM – Global GMPEs Task 2 WG Report, 2011).

3.3. Task 3: Select a Global Set of GMPEs

For the GEM applications of hazard analysis at global level, a small number of GMPEs has to be selected. This set is smaller than usually used for detailed site-specific hazard analyses. In this task, the set of pre-selected models compiled and screened in Task 2 will be reduced to a more manageable number for GEM global hazard assessments. It should also be noted that GMPE development is an area of on-going research and new and/or updated GMPEs are continuously developed as new data and simulations results become available and the knowledge of ground motion hazard is expanded; thus, the recommendations of Task 3 should not be considered as a permanent selection.

To ensure self-consistency in the selection approach, the WG of international experts has agreed on a set of few features of the GMPEs to emphasize in the selection. Accordingly, GMPEs derived from international data sets have been preferred over models derived from local data sets. Additionally, the WG recognized attributes in the GMPEs functional forms which were deemed desirable, including saturation with magnitude, magnitude-dependent distance scaling, and anelastic attenuation terms. During the selection process, if multiple GMPEs well-constrained by data but exhibiting different trends were present, they may be chosen to capture the epistemic uncertainty.

Table 2. List of pre-selected models for the main seismo-tectonic regimes in the GEM – PEER Global GMPEs project

Stable Continental	Atkinson (2008) as modified by Atkinson & Boore (2011): Referenced empirical model for eastern North America
	Atkinson & Boore (2006) as modified by Atkinson & Boore (2011): Extended stochastic model for eastern North America
	Campbell (2003): Hybrid model for eastern North America
	Douglas et al. (2006): Hybrid model for southern Norway
	Frankel et al. (1996) as parameterized by EPRI (2004): Stochastic model for eastern North America
	Pezeshk et al. (2011): Hybrid model for eastern North America
	Raghu Kanth & Iyengar (2006, 2007): Peninsular India
	Silva et al. (2002): Stochastic model for eastern North America
	Somerville et al. (2009): Simulation-based models for Australia
	Toro et al. (1997), originally published in EPRI (1993), modified by Toro (2002): Stochastic model for eastern North America
Subduction	BC Hydro Model, Abrahamson et al. (2012): Worldwide
	Arroyo et al. (2010): Interface model for Mexico (complementary to Garcia et al., 2005))
	Atkinson & Boore (2003): Worldwide
	Garcia et al. (2005): Intraslab model for Mexico (complementary to Arroyo et al., 2010)
	Kanno et al. (2006): Japan
	Lin & Lee (2008): Taiwan
	McVerry et al. (2006): New Zealand
	Youngs et al. (1997): Worldwide
	Zhao et al. (2006) with modifications by Zhao (2010): Japan
Shallow crustal in tectonically active regions	Abrahamson & Silva (2008): NGA model using worldwide data
	Akkar & Bommer (2010): Model using Mediterranean and Middle Eastern data
	Boore & Atkinson (2008) as modified by Atkinson & Boore (2011): NGA model using worldwide data
	Campbell & Bozorgnia (2008) : NGA model using worldwide data
	Cauzzi & Faccioli (2008) as updated by Faccioli et al. (2010): Model using worldwide data (mainly Japanese)
	Chiou & Youngs (2008): NGA model using worldwide data
	Kanno et al. (2006): Model using mainly Japanese data
	McVerry et al. (2006): Model using mainly New Zealand data
	Zhao et al. (2006): Model using mainly Japanese data

Building on those features, the selection process has been based on reviewing how well the GMPEs fit the available worldwide data for the applicable tectonic category. First, for each model, the WG carefully reviewed the multi-dimensional scaling and the functional form parameterization with respect to the main predictive parameters. For this purpose, so-called trellis plots were made showing spectral shapes for various magnitude and distance combinations, magnitude-scaling trends for different distance bins, distance-scaling trends for different magnitude bins, site effect terms, hypocentral depth-scaling terms, and standard deviation terms. Figure 1 presents an example of trellis plot showing predicted response spectra (PSA) for a variety of magnitude-distance combination within the range of interest.

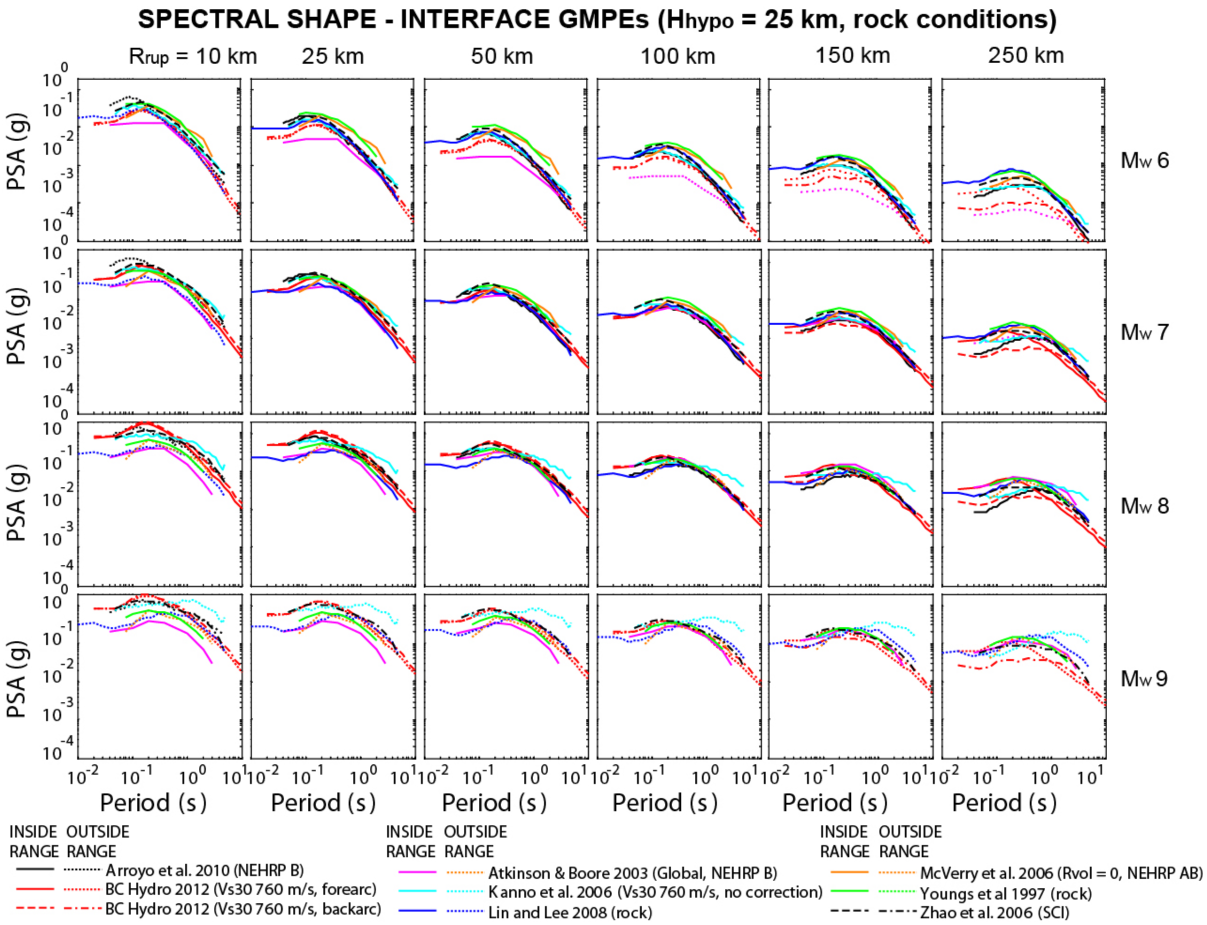

Figure 1. Trellis chart showing predicted PSAs for pre-selected subduction GMPEs for various interface earthquake scenarios for rock site conditions. Dashed lines indicated where the scenario falls outside the magnitude-distance range of validity of the model.

Such plots help the evaluation of how the spectra predicted by each GMPE compare to the others, and also to assess if some models show a consistent deviation with respect to the overall trend of the other models for specific magnitude, distances or spectral periods. Because the goal of the project is to propose ground-motion models that work over wide ranges of interest to GEM, the experts also evaluated how the GMPEs performed for magnitudes and distances outside the limits of applicability stated by the GMPE developers (shown by dotted lines).

The WG also compiled and reviewed published quantitative tests discussing performances of the GMPEs against observed data not used for their derivation. Emphasis was given to those studies that undertook formal analysis of residuals (possibly including their partition into inter- and intra-event residuals) to provide insight into GMPEs performance. For this purpose, published literature was examined where the following two general methods of residual analyses were performed: (1) the maximum likelihood approach of Scherbaum et al. (2004, 2009) and its extension to normalized intra- and inter-event residuals distributions by Stafford et al. (2008), which are intended to judge the overall fit of model to data; and (2) analysis of intra- and inter-event residuals specifically targeted to investigations of GMPE scaling with respect to magnitude, distance, and site parameters (Scasserra et al., 2009).

Based on the described procedure, for each tectonic category a preliminary subset of the global GMPEs has been selected. For the preliminary selected GMPEs, the project has summarized its attributes, such as the characteristics of its database (e.g., number of earthquakes, number of recordings, magnitude and distance ranges in the database, etc.), applicability of the GMPEs for ranges of distance, magnitude, site effect, etc. In the companion paper by Stewart et al. (2012b), the evaluation process used for subduction regions, treated as an example of the method applied for each of the other tectonic categories comprised in the project, is presented and summarized. The final selection of GMPEs for GEM global applications will be made after a large face-to-face meeting in Istanbul, Turkey in May 2012.

3.4. Task 4: Include Near-Fault Effects

Under this task, various existing adjustments of GMPEs to include near-fault effects such as directivity and directionality have been examined and recommendations for adoption by the GEM project will be developed. Accounting for those adjustments is critical for a realistic PSHA estimation, because most GMPEs do not provide predictions that account explicitly for near-fault effects, such as rupture directivity, or capture polarization of response spectra in the near-fault region. A variety of models are available to possibly modify GMPE predictions to account for those effects. In addition to the standard GMPE parameters such as earthquake magnitude and distance, these models typically use the earthquake hypocenter location, and possibly other information about slip direction, to infer whether a given site is likely to experience directivity effects, and amplifies or de-amplifies the GMPE prediction appropriately.

The companion paper by Baker et al. (2012) presents an overview of published methods for adjusting GMPEs to include near-fault effects.

3.5. Task 5: Build an Inventory of Recorded Waveform Databases

This task is designed to provide users with various Internet links to the databases either collected as part of the GEM Global GMPEs, or the databases already developed as part of other projects such as NGA, SHARE, etc. For data for which permissions has been granted, (considering legally issues such as copyrights), the users can download the data and metadata from these databases. Collection of new ground motion data and new metadata are beyond this task.

3.6. Task 6: Design the Specifications to Compile a Global Database of Soil Classification

Task 6 represents a continuation of Task1b. It aims at defining and proposing, through expert consensus, a set of specifications for a future work by the GEM Foundation. The main objective of this task it to provide a hierarchically organized set of recommendations to compile a consistent global database of soil classifications based on V_{s30} and designed to be consistent with the soil categories in the NEHRP and EuroCode 8 building codes. If the soil categories used in the selected Global GMPEs (Task 3) are not consistent with the selected soil categorization scheme, they will be mapped to this scheme based on the methodology developed in Task 1b. In this manner, only a single global site categorization scheme and site map will be used. For basins, information on depth to basement rock is recognized to be an important site parameter, and therefore specification on how to compile this type of data is provided; however, the actual estimation or compilation of worldwide depths to basement rock and of soil data is beyond the scope of this task.

4. CONCLUDING REMARKS

In this paper, we have presented an overview of the Global GMPEs project being carried out by a distinguished panel of international experts coordinated by the Pacific Earthquake Engineering Research Center (PEER). The contributions of the GEM project includes a set of consensus-based, best practice approaches and recommendations for characterizing ground motion for implementing in the OpenQuake seismic hazard engine. In this perspective, the process, principal findings, along with the main recommendations presented in this and other companion papers, meets the requirements indicated by GEM for being part of its Global Hazard Components. The project will be finalized in late 2012 and all tasks' will be documented in a PEER report. It's worth noting that the recommendations of the project are based on the current state of knowledge on ground-motion hazard, and that GMPE development is a continuously evolving research area as new and/or updated GMPEs are being developed using fast growing empirical data sets and simulated data based on well-calibrated models. Thus, the recommendations proposed by this project should not be viewed as a very long-term perspective and they are subject to change.

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