Design Ground Motion Library (DGML): An Interactive Tool for Selecting Earthquake Ground Motions

Gang Wang, a) M.EERI, Robert Youngs, b) M.EERI, Maurice Power, b) M.EERI, and Zhihua Li, b) M.EERI

Design Ground Motion Library (DGML) is an interactive tool for selecting earthquake ground motion time histories based on contemporary knowledge and engineering practice. The ground motion database used consists of 3182 records from shallow crustal earthquakes in active tectonic regions rotated to fault-normal and fault-parallel directions. The DGML enables users to construct design response spectra based on the Next Generation Attenuation relationships, including conditional mean spectra, code spectra and user-specified spectra. The DGML has the broad capability of searching for time history record sets in the database on the basis of similarity of response spectral shape of a record to a design response spectrum over a user-defined period range. Selection criteria considering other ground motion characteristics and user’s need are also provided. The DGML has been adapted for web-based application by Pacific Earthquake Engineering Research Center (PEER) and incorporated as a Beta Version on the PEER database website (http://peer.berkeley.edu/peer_ground_motion_database/).

INTRODUCTION

In performance-based seismic design of civil structures, it is critical to develop systematic methods and useful tools to search, select and modify suitable ground motion time histories for engineering applications. In a project sponsored jointly by the California Geological Survey-Strong Motion Instrumentation Program (CGS-SMIP) and the Pacific Earthquake Engineering Research Center-Lifelines Program (PEER-LL), a multidisciplinary team including geotechnical engineers, seismologists, and structural engineers developed a Design Ground Motion Library (DGML) (AMEC Geomatrix, Inc. 2009).

a) Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
b) AMEC Environment & Infrastructure, 2101 Webster Street, 12th Floor, Oakland, CA 94612, USA
Since only a limited number of ground motion records are available for rare design-level events, amplitude scaling of ground acceleration is commonly performed in earthquake engineering design practice. However, ground motion scaling has been a subject of intensive debate over years, as inappropriate record scaling can bias estimated structural response (e.g., Luco and Bazzurro 2007). Significant concerns have been raised regarding the validity of the scaling process in several studies (e.g., Grigoriu 2011). On the other hand, it has been reported that the degree of bias induced by record scaling can systematically decrease as more constraints are applied on the ground motion selection and scaling process (Hancock et al. 2008). In terms of geotechnical application, Watson-Lamprey and Abrahamson (2006) demonstrated that ground motions can be scaled by large factors and still lead to unbiased estimate of earthquake-induced sliding displacements for slopes, if ground selection and scaling are based on multiple well-selected parameters. In terms of structural response, the elastic response spectrum over a period range of significance has been found to be closely correlated to inelastic structural response in a number of studies (e.g. Shome et al. 1998; Baker and Cornell 2005, 2006). The period range of significance may include periods shorter than the fundamental structure period because of higher-mode effects and periods longer than the fundamental structure period because of structure softening during inelastic response. Recently, benchmark tests were conducted by the PEER Ground Motion Selection and Modification (GMSM) Working Group to quantify the accuracy of various GMSM schemes in predicting median inter-story drift response of buildings (Haselton 2009). The results demonstrated the importance of scaling records to account for the realistic spectral shape of ground motions at the design level. Especially, the conditional mean spectrum (CMS) describes the expected distribution of spectral accelerations at different periods for a scenario earthquake (Baker and Cornell, 2006; Baker 2011). Ground motion records scaled to match the CMS have realistic spectral shape at multiple periods, so they can better estimate the median inter-story drift of buildings in that study (Haselton 2009). To explicitly account for the inelastic behaviors of structures, ground motion scaling methods are also developed by using inelastic deformation spectrum or the response of the first-mode inelastic single-DOF system (e.g., Luco and Cornell 2007, Kalkan and Chopra 2010, Reyes and Chopra 2012). In these procedures, important structure-specific properties such as the modal participation factors and the structural strength other than the fundamental structure period alone can be explicitly considered.
In summary, realistic estimates of inelastic response for different types of structures requires ground motion selection and scaling to be properly conducted, by taking into account the structural characteristics and single or multiple ground motion parameters that are significantly correlated to the structural response. These considerations, as well as considerations of a range of preferences by designers and analysts (such as the size of the time history sets) indicated that a “dynamic” ground motion library was needed, i.e. a library permitting the tailoring of the selection of time history records to specific project needs and designer preferences. One of the objectives of developing the DGML was to create an efficient tool for time history selection that is consistent with contemporary knowledge and engineering practice. The DGML enables the rapid searching and selection of the time histories from a large ground motion database based on appropriate criteria and user needs. The DGML has the broad capability of searching for time history record sets in the library database on the basis of (1) the characteristics of the recordings in terms of earthquake magnitude, type of faulting, distance, and site characteristics, (2) the response spectral shape of the records in comparison to design or target response spectra, and (3) other record characteristics including duration and the presence of velocity pulses in near-fault time histories. Other criteria and limits can be specified by the user to constrain searches for time histories. Also, supplemental searches can be conducted for individual records or records from selected earthquakes or stations and these records can be evaluated and incorporated in data sets of search results. Initially developed on a DVD-ROM, the DGML has been adapted for internet web-based application by PEER and incorporated as a Beta Version on the PEER database web site (http://peer.berkeley.edu/peer_ground_motion_database/). This paper summarizes the development of the DGML and its application in selecting and scaling earthquake ground motions for seismic design of civil structures.

EARTHQUAKE GROUND MOTION DATABASE

(1) DGML Strong Motion Database

The source of the database for the DGML is the PEER Next-Generation Attenuation (PEER-NGA) project database of ground motion recordings and supporting information (http://peer.berkeley.edu/nga/). This database was developed as the principal resource for the development of updated ground motion prediction equations (GMPEs) in the NGA research project coordinated by PEER-Lifelines Program (PEER-LL), in partnership with the U.S. Geological Survey (USGS) and the Southern California Earthquake Center (SCEC) (Chiou et
al. 2008; Power et al. 2008). The database represents a comprehensive update and expansion of the pre-existing PEER database. The ground motion records are originally from strong motion networks and databases of CGS-SMIP and U.S. Geological Survey (USGS) and other reliable international sources. The PEER NGA database includes 3551 three-component recordings from 173 earthquakes and 1456 recording stations. The DGML database consists of 3182 records from the PEER-NGA database; 369 records were not included in the DGML database for various reasons including one or more of the following: (a) records considered to be from tectonic environments other than shallow crustal earthquakes in active tectonic regions, e.g. records from subduction zones; (b) earthquakes with poor quality metadata; (c) records obtained in recording stations not considered to be sufficiently close to free-field ground surface conditions, e.g. records obtained in basements of buildings or on the ground floors of tall buildings; (d) absence of information on soil/geologic conditions at recording stations; (e) records having only one horizontal component; (f) records not rotated to fault-normal (FN) and fault-parallel (FP) directions because of absence of information on sensor orientations or fault strike; (g) records of questionable quality; (h) proprietary data etc. Figure 1 shows the magnitude and distance distribution of the included records in the DGML database.

![Figure 1](image_url)

**Figure 1.** Magnitude and rupture distance distribution for PEER NGA records in DGML database.

Acceleration time histories in the DGML are horizontal components that have been rotated to FN and FP directions. The use of rotated time histories in the DGML does not imply that they are for use in time history analyses in FN and FP directions only, and they
can be used in time history sets in the same manner as time histories in the as-recorded orientations in other databases. The rotation to FN and FP directions does, however, provide additional information with respect to the seismological conditions under which the recordings were obtained, and, as studied previously, records in the FN direction have been found to often contain strong velocity pulses that may be associated with rupture directivity effects (Somerville et al. 1997).

Ground motion parameters quantified for time histories in the DGML database are response spectra, peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), significant duration, assessments of the lowest usable frequency (longest usable period) for response spectra, and presence and periods of strong velocity pulses. The recommended lowest usable frequency is related to filtering of a record by the record processing organization to remove low-frequency (long-period) noise. High-pass filtering results in suppression of ground motion amplitudes and energy at frequencies lower than the lowest usable frequency such that the motion is not representative of the real ground motion at those frequencies. It is a user’s choice in DGML on whether to select or reject a record on the basis of the lowest usable frequency. Because of the suppression of ground motion at frequencies lower than the lowest usable frequency, it is recommended that selected records have lowest usable frequencies equal to or lower than the lowest frequency of interest.

A major effort was made in the PEER-NGA project to systematically evaluate and quantify supporting information (metadata) about the ground motion records. Metadata in the PEER-NGA database include: earthquake source information (e.g. moment magnitude; type of faulting (mechanism); depth to the top of fault rupture; rupture directivity parameters); source-to-recording station-site travel path information (e.g. different measures of source-to-site distance; recording station location on hanging wall or footwall of reverse or normal fault); local site conditions at recording stations (e.g. average shear wave velocity in upper 30 meters of sediments, $V_{S30}$; depth to basement rock). Metadata that have been included for records in the DGML database are: earthquake magnitude and type of faulting; measures of closest distance from earthquake source to recording station site (closest distance to fault rupture surface and Joyner-Boore distance); and site $V_{S30}$. The DGML also provides access to the vertical ground motion time histories and their response spectra if available.
(2) Records with Velocity Pulses

A number of studies have shown that strong velocity pulses in ground motion time history records, such as often occur in near-source ground motions due to near-source fault rupture directivity effects, can impose severe demands on structures (Bertero et al. 1978; Hall et al. 1995; Alavi and Krawinkler 2001; Makris and Black 2003; Mavroeidis et al. 2004; Akkar et al. 2005; Luco and Cornell 2007). The presence of velocity pulses in records can be a criterion in searches for records in the DGML.

Within the PEER-NGA database, certain ground motion records have been identified as having strong velocity pulses that may be associated with fault rupture directivity effects. The following general criteria were adopted in this project to define records with velocity pulses (Baker 2007): (1) the pulse is large relative to the residual features of the ground motion after the pulse is extracted; (2) the pulse arrives early in the time history, as would be expected for pulses associated with rupture directivity effects; and (3) the absolute velocity amplitudes are large (PGV of the pulse record should be equal to or greater than 30 cm/sec). Although prior research (Somerville et al. 1997) has indicated that the strongest pulses are generally more closely aligned with the FN direction than the FP direction, the above criteria were applied to both FN and FP components of ground motions in the NGA database. More detailed results and documentation of analyses are contained on the website http://www.stanford.edu/~bakerjw/pulse-classification.html. It is also interesting to point out that even though some records may not have apparent velocity pulses in the FN or FP direction, velocity pulses may be presented in other directions (Reyes and Kalkan 2012). However, the pulse records identified in the DGML are only for the FN and FP components.

Besides the pulse records indentified by Baker (2007), several additional records having strong FN pulses were also included in the DGML if the records had been identified as pulse records in at least two studies by other researchers (Somerville 2003; Mavroeidis and Papageorgiou 2003; Bray and Rodriguez-Marek 2004; Fu and Menon 2004), and the PGV of these records was equal to or greater than 30 cm/sec (same as Baker’s criterion). In total, pulse records have been identified in the DGML database as follows: 63 records having pulses in the FN components only; 23 records having pulses in the FP components only; and 30 records having pulses in both FN and FP components. The DGML user interface enables searching for these pulse records; searches can be made for records having FN pulses, FP
pulses, or both FN and FP pulses. Similar to other records in the DGML, a user can also specify criteria and limits described in the following section in searches for pulse records.

Note that there can be no assurance that velocity pulses of records in the DGML database are all due to directivity effects without more detailed seismological study of individual records. It is likely that other seismological factors may have caused or contributed to the velocity pulses of some records. However, while the causative mechanisms for the pulses are uncertain, it is expected that the pulses are similar to those caused by directivity and therefore suitable for use in modeling effects of directivity pulses on structures. Besides the commonly used ground motion parameters as described in the previous section, the DGML also provides estimates of pulse periods for all identified pulse records, which are primarily based on Baker (2007) except for these few records added. In order to obtain a more detailed understanding of the nature of pulses in time history records considered for analysis, it is suggested that the velocity time histories of candidate time histories be displayed and examined. This can be readily done through the DGML graphic interface.

GROUND MOTION SELECTION CRITERIA AND PROCEDURES

The selection of ground motions by the DGML is based on response spectral shape and other criteria in a three-step process: (1) specification of the design or target response spectrum; (2) specification of criteria and limits for conducting searches for time history records; and (3) search of database and selection and evaluation of records. The flow chart of the DGML is illustrated in Figure 2.

![Flow chart of the DGML](image.png)

**Figure 2.** Flow chart of the DGML.
(1) Developing the Target Spectrum

The DGML “Target Spectrum” window is shown in Figure 3. The window contains the following main parts: (1) Select spectrum model; (2) PEER-NGA spectrum; (3) User defined spectrum; (4) Code spectrum; (5) Plot control panel; (6) Spectrum plot; (7) Explanation of notations; (8) “Save Target Spectrum” button; (9) Go to “Next” step to perform DGML search.

Three options are provided within the DGML for developing the target spectrum:

Option 1: Code Spectrum. For this option, the target spectrum is the design earthquake spectrum or the maximum considered earthquake (MCE) spectrum as formulated in the NEHRP Provisions (FEMA 2009), ASCE Standard ASCE 7-05 (ASCE 2006), ASCE 7-10 (ASCE 2010) and the International Building Code (ICC 2006). The Code design spectrum is completely specified by three parameters which are obtained using the design ground motion
maps and other provisions in the Code document: site-class-adjusted 0.2 second spectral acceleration, $S_{DS}$; site-class-adjusted 1.0-second spectral acceleration, $S_{DI}$; and the transition period, $T_L$, from constant spectral velocity (for which spectral accelerations are proportional to $1/T$) to constant spectral displacement (for which spectral accelerations are proportional to $1/T^2$). The user enters the values for these three parameters and the DGML constructs and plots the response spectrum.

Option 2: User-Defined Spectrum. The user may enter any response spectrum as a table of periods and response spectral accelerations and the tool constructs and plots the spectrum. Such response spectra may be either probabilistic (uniform hazard spectrum, UHS) or deterministic (scenario earthquake) response spectra developed by the user.

Option 3: Scenario spectrum based on the PEER-NGA models. For this option, DGML constructs a deterministic scenario earthquake spectrum using a user-selected set of ground motion prediction models developed in the NGA project for shallow crustal earthquakes in active tectonic regions. Five ground-motion prediction equations (GMPEs) were developed in the NGA project: Abrahamson and Silva (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008), Chiou and Youngs (2008), and Idriss (2008). The user enters the earthquake parameters, travel path parameters, and site parameters (e.g., earthquake moment magnitude, type of faulting, fault-to-site distance, site shear wave velocity in the upper 30 meters ($V_{S30}$), and other parameters needed for the selected NGA models), and the DGML constructs the individual response spectra and an average of the spectra for the models.

The DGML also has the capability to construct the conditional mean spectrum (CMS) for a scenario earthquake. Although sets of time histories are often formed in practice to provide an aggregate match to a probabilistic response spectrum (uniform hazard spectrum, UHS) for design purposes, there may be conservatism involved in doing so. As summarized by Cornell (2006) and Baker (2011), the UHS is different from the response spectrum expected for a single ground motion from a scenario earthquake. The spectral ordinates of a UHS at different periods may be driven by two or more different scenario earthquake sources and therefore the UHS may be overly broad and thus conservative for a single earthquake. On the other hand, conditional mean spectra can provide realistic spectral shapes for scenario earthquakes.

To construct conditional mean spectra, hazard deaggregation should be carried out first to identify the dominant deterministic earthquake scenarios, including their magnitudes ($M$) and
rupture distances \((R)\), contributing to a UHS. The “epsilon”, \(\varepsilon(T_0)\), measures the number of standard deviations between the median spectrum of a scenario earthquake (based on \(M, R\)) and a given target spectral acceleration value at period \(T_0\) as follows:

\[
\varepsilon(T_0) = \frac{\ln \text{Sa}_{\text{target}}(T_0) - \ln \text{Sa}(M, R, T_0)}{\sigma_{\ln \text{Sa}(T_0)}}
\]

where \(\ln \text{Sa}_{\text{target}}(T_0)\) is the specified target value of the logarithmic spectral acceleration at \(T_0\), and \(\ln \text{Sa}(M, R, T_0)\) and \(\sigma_{\ln \text{Sa}(T_0)}\) are the predicted mean and standard deviation, respectively, of the logarithmic spectral acceleration at period \(T_0\) provided by the NGA models. The DGML allows the user to specify the \(\varepsilon(T_0)\) value directly to construct the conditional mean spectrum from the following equation (Baker and Cornell 2006; Baker 2011):

\[
\ln \text{Sa}^*(T) = \ln \text{Sa}(M, R, T) + \rho(T, T_0) \times \sigma_{\ln \text{Sa}(T)} \times \varepsilon(T_0)
\]

where \(\ln \text{Sa}^*(T)\) is the conditional mean spectrum at period \(T\), conditioned on a given target spectral acceleration value at period \(T_0\); and \(\rho(T, T_0)\) is the correlation coefficient between (logarithmic) spectral accelerations at \(T\) and \(T_0\) (e.g. Baker and Jayaram 2008).

Figure 4 illustrates construction of a conditional mean spectrum by the DGML. For this example, the median and median + 1.5 standard deviation spectra are constructed using the NGA models based on a deterministic scenario (\(M_w = 7, R_{rup} = 10\) km, strike-slip faulting, and rock site). The conditional mean spectra are conditional on the spectral
acceleration at the level of 1.5 epsilon at the periods of 0.5 sec and 1 sec, respectively, as is specified by the DGML in this example. Multiple conditional mean spectra can be constructed for different conditioning periods. Figure 4(b) illustrates conceptually the construction of conditional mean response spectra for different periods for two scenario earthquakes in order to more closely match, in aggregate, a UHS design spectrum. As shown in Figure 4(b) for scenario earthquakes A and B, a single conditional mean spectrum for each earthquake could fall substantially below the UHS at periods distant from the period at which the conditional mean spectrum is at the target epsilon. Therefore, as shown in the figure, two (or more) conditional mean spectra could be required for each scenario earthquake to satisfy code requirements for an aggregate match to the design UHS.

(2) Specifying Criteria and Limits for Searches

A basic criterion used by the DGML to select a representative acceleration time history is that the spectrum of the time history provides a “good match” to the user’s target spectrum over the spectral period range of interest defined by the user. The quantitative measure used to evaluate how well a time history conforms to the target spectrum is the mean squared error (MSE) of the difference between the spectral accelerations of the record and the target spectrum, computed using the logarithms of spectral period and spectral acceleration. The DGML tool searches the database for records that satisfy general acceptance criteria provided by the user and then ranks the records in order of increasing MSE, with the best-matching records having the lowest MSE. It is worth pointing out that the target spectrum developed using options 1 to 3 in the previous section and the response spectrum of individual records in the database are all linearly interpolated in the log-log scale using a set of periods equally-spaced from 0.01 seconds to 10 seconds in log scale (100 points/log cycle, therefore 301 periods from 0.01 to 10 seconds with end points included). The MSE is computed using the interpolated data via Equation (3):

$$\text{MSE} = \frac{\sum_i w(T_i) \left( \ln \left[ S_a^{\text{target}}(T_i) \right] - \ln \left[ f \times S_a^{\text{record}}(T_i) \right] \right)^2}{\sum_i w(T_i)}$$

(3)

where parameter $f$ is a linear scale factor applied to the entire response spectrum of the recording. Parameter $w(T_i)$ is a weight function that allows the user to assign relative weights to different parts of the period range of interest, providing greater flexibility in the selection of records. The simplest case is to assign equal weight to all periods (i.e. $w(T_i) = 1$), but the
user may wish to emphasize the match over a narrow period range of interest while maintaining a reasonable match over a broad period range.

The DGML allows the user to select individual FN/FP component recordings that provide a good match to the target or, alternatively, select recordings for which the geometric mean of the two horizontal FN and FP components provides a good match to the target spectrum. In this latter case the MSE is computed over both components using Equation (3) with the same value of $f$ applied to both components. This process maintains the relative amplitude of the two horizontal components.

Amplitude scaling of “as recorded” strong ground motion acceleration time histories is used in the DGML, which does not alter the frequency content of the recordings. The user has three options for scaling. One option is to apply a scale factor that minimizes the MSE over the period range of interest. This approach produces scaled recordings that provide the best match to the spectral shape of the target spectrum over the user-specified period range of interest. Minimization of the MSE as defined in Equation (3) is achieved by a scale factor given by the mean weighted residual in natural logarithm space between the target and the record spectra:

$$
\ln f = \sum_i w(T_i) \ln \left( \frac{Sa_{\text{target}}(T_i)}{Sa_{\text{record}}(T_i)} \right) / \sum_i w(T_i)
$$

(4)

The second option is to scale the records so that the spectral acceleration at a single period matches the target spectral acceleration at that period. This option can be used to scale a set of records to have the same spectrum ordinate as the target conditional mean spectrum at the conditioning period $T_0$. In this case the scale factor is determined by:

$$
f = \frac{Sa_{\text{target}}(T_0)}{Sa_{\text{record}}(T_0)}
$$

(5)

A third option of applying no scaling is also available. For all three scaling options, the MSE is computed using Equation (3). Note that for all options, it is necessary for the user to specify the weight function because it is used to calculate the MSE and order the results with respect to the degree of match between target spectrum and spectra of recordings over the user-specified period range of significance. In DGML, the weight function is also discretized at each $T_i$. The weight function only represents relative weights assigned to various discrete
periods and are normalized in the program such that the summation of the weight function over discrete period points equals unity. Therefore, the absolute value of the weight function is immaterial.

The user specifies the ranges of parameters over which searches are to be conducted and other limits and restrictions on the searches. These may include: earthquake magnitude range; type of faulting; distance range; $V_{S30}$ range; significant duration range; whether records are to exclude, include, or be limited to pulse records; limits on the scale factor $f$; and restrictions on directional component (i.e., arbitrary FN or FP components [no restriction]; FN components only; FP component only; or FN and FP components in pair).

Other criteria to be specified by the user are (1) total number of records for the search that will be displayed; and (2) total number of records for which the average spectrum will be calculated. Figure 5 illustrates the DGML “Search Engine” graphic interface used to specify primary search criteria and list and plot search results including time histories and individual and average response spectra of scaled records sets compared to a specified design or target spectrum. Eight main function modules are: (1) “Search Engine” to specify the record acceptance criteria and perform search over the database; (2) Specification of weight function used for scaling records; (3) Spectra plotting window; (4) Weight function plot window; (5) Acceleration/velocity/displacement time history plotting of a selected record (one-, two-, or three-component time histories of a record can also be viewed at an expanded time scale, if desired to examine details of the time histories, using a feature called “Zoom in Time”); (6) Ground motion record information output list; (7) Graphic control panel for line styles and display of ground motion components; and (8) Buttons to accept or reject individual records and to save the search results and selected acceleration time history files. Figure 6 illustrates an example of individual spectra and the average spectrum of selected records compared with the target spectrum. Figure 7 highlights the spectra of three-components (FN, FP and vertical) of an individual record, as well as the acceleration, velocity and displacement time histories of the record.

**3) Selection and Evaluation of Ground Motion Records**

The software tool scans the database, selects all records meeting user-specified criteria as summarized above, scales records to match the target spectrum, and ranks records in order of increasing MSE. The software tool also has a “Supplementary Search” function to search for specific records according to specified NGA record sequence number or by earthquake name.
or recording station name. Selected records from a “Supplementary Search” are scaled and ranked by MSE and can be incorporated into final data sets as desired by the user. This search capability was added so that users can examine any record or group of records and further fine-tune the search results based on user preferences.

![DGML LibPostProcessor](image)

**Figure 5.** The DGML “Search Engine” interface.

For a selected record set, a “Search Report” can be automatically generated and exported by DGML, including: summary of search criteria; summary of earthquake, distance, and station/site information; record scaling factors and MSEs; scaled record characteristics including PGA, PGV, PGD, response spectral accelerations, presence of pulses and pulse periods, significant durations, and recommended lowest usable frequencies; and scaled average spectral accelerations for the selected record set along with the target or design spectral accelerations. The Search Report can be saved as an Excel spread-sheet file. Although the search results are based on horizontal records, the response spectra for corresponding vertical records, scaled by the same factors as for the horizontal records, can
also be saved together with their horizontal counterparts in the search report. Spectra and
time history plots can be saved as figure files. The horizontal and/or vertical components of
the selected acceleration time histories can also be saved; the saved time histories are the
unscaled original data from the PEER-NGA database.

![Graph](image)

**Figure 6.** Example of average spectrum of selected records.

![Graph](image)

**Figure 7.** Highlight of the response spectrum and time history of an individual record. (a) FN, FP and vertical response spectrum (b) FN, FP acceleration, velocity and displacement time histories.

The user can further modify the time histories if required or desired for other purposes
(e.g., fine-tune record scaling factors to meet building code requirements; rotate time
histories; or adjust the match of record spectra to a design spectrum through frequency
content altering methods etc.). For example, ASCE 7-05 and 7-10 specify that for two-
dimensional analysis the average value of the 5 percent-damped response spectra for the set
of time histories used shall be not less than the design response spectrum for periods ranging
0.2\(T_1\) to 1.5\(T_1\) where \(T_1\) is the natural period of the structure in the fundamental mode for the
direction of response being analyzed (ASCE 2006, 2010). This criterion can be easily checked using the average of the spectra for the scaled time histories provided by the DGML Search Report output in Excel format and then applying any minor adjustment factor to the set of records to meet the criterion.

For three-dimensional analysis of structures, ASCE 7-10 requires that in the period range $T_i$ from $0.2T_i$ to $1.5T_i$ the average of the square root of the sum of squares (SRSS) spectra \( \left( \sqrt{Sa_{\text{F}N}(T_i)} + Sa_{\text{FP}}(T_i) \right) \) from all time history pairs does not fall below the corresponding ordinate of the response spectrum used in the design. Again, with a little more effort, the criterion can be checked using the DGML output in Excel format. The user would first compute the SRSS spectrum for each pair of time histories, then compare the average of the SRSS spectra with the design spectrum. Figure 8 illustrates the process. The DGML scales the selected time histories on the basis of comparing the geometric mean for each pair of records to the target spectrum. The average of the geometric mean spectra selected by the DGML provides a good match to the target design spectrum. The corresponding average of the SRSS spectra has a similar shape to the average of the geometric mean spectra, but is higher as expected. Comparison of the average SRSS spectrum with the design spectrum in the period range of interest provides a scale factor (0.76 in this case) that can be applied to the suite of selected records to meet the criterion.

For the special three-dimensional analysis case of sites located within 3 miles (5 km) of the active fault that controls the hazard, ASCE 7-10 requires that each pair of components shall be rotated to fault-normal and fault-parallel directions of the causative fault and scaled so that the average of the FN components is not less than the risk-targeted maximum considered earthquake (MCE$_R$) response spectrum. Meeting this criterion can be facilitated by using the DGML by first defining a target spectrum as the MCE$_R$ spectrum and searching for “FN components only” and then adjusting the scaling of the FN components to meet the criterion in the same way as for the two-dimensional analysis case. The pairing FP components shall be scaled by the same factors.

![Figure 8](image-url)  
**Figure 8.** Adjustment of the selected ground motion records to the ASCE 7-10 code design spectrum for three dimensional analysis.
SUMMARY AND DISCUSSION

The successful development of the DGML is the outcome of a multidisciplinary team effort. It represents a state-of-the-art software package that enables interactive selection and modification of time histories for dynamic analysis of structures based on appropriate selection criteria and user needs. The DGML facilitates the construction of design response spectra using recently-developed NGA relationships, including “conditional mean spectra”, as well as to construct code spectra and any other user-specified spectra. The DGML has the broad capability of searching for time history record sets in the library database on the basis of the response spectral shape, the characteristics of the recordings in terms of earthquake magnitude and type of faulting, distance, site characteristics, duration and the presence of velocity pulses in near-fault time histories.

DGML features a friendly graphic user interface (GUI) to facilitate data input, visualization and processing. Results in each step can be visualized, and results for different sets of input parameters can be easily compared. Users can inspect the response spectra and acceleration/velocity/displacement time-histories for each individual record for each component. The DGML also provides easy ways to output search results, plots and tables. Files containing acceleration time histories of selected records can be saved for each project. The algorithm of the DGML package is robust and efficient. The search engine can scan and sort the database within a few seconds.

It is also worth pointing out that ground motions selected by the DGML mainly aim at estimating the median response of structures based on an elastic target spectrum. Sometimes, it is important to obtain the actual dispersion of the structural behaviors in the performance-based earthquake design. For this purpose, ground motion selection algorithms for matching the target response spectrum mean and variance have been recently developed (Wang 2011, Jayaram et al. 2011). These new development can be readily implemented in the DGML in the future.

The prototype of DGML was developed using Matlab ® (version 7.2) Graphic User Interface (GUI) and it can be executed or modified in the Matlab environment. The DGML Matlab codes were subsequently compiled into a standalone executable using Matlab Compiler® so that the Matlab environment is not required for end users. The compiled DGML package (Version 2) was released on a DVD-ROM format and distributed to a small
group of experts for testing, evaluation and review in 2009. DGML has been adapted for internet web-based application by PEER and incorporated as a Beta Version on the PEER database website (http://peer.berkeley.edu/peer_ground_motion_database/). The web-based application enables broad access of the ground motion selection tool.

The DGML is currently limited to recorded time histories from shallow crustal earthquakes in active tectonic regimes. With the completion of the PEER NGA-West 2 program, a greatly expanded ground motion database (Ancheta et al. 2013) and updated attenuation relationships have been developed and can be incorporated to enhance the capability of the DGML. Time histories from subduction zone earthquakes are not part of the DGLM during this project. However, future developments of the DGML could add records from subduction zone earthquakes (appropriate for these types of earthquakes occurring in coastal regions of northwest California, Oregon, Washington, and Alaska) and could also supplement the library of recorded time histories with time histories simulated by ground motion modeling methods. The DGML can be easily upgraded to accommodate these future developments.

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