THE IMPORTANCE OF CONSIDERING SPECTRAL SHAPE WHEN EVALUATING BUILDING SEISMIC PERFORMANCE UNDER EXTREME GROUND MOTIONS

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Abstract

Recent research has shown that considering ground motion spectral shape is important when using nonlinear dynamic analysis to predict seismic structural response under extreme ground motions (such as a 2% in 50 year of Maximum Considered Earthquake motion). Using a 20-story reinforced concrete frame building, this paper presents quantitative comparisons of interstory drift predictions using 10 ground motion selection methods, some of which are based on building code methods, while the other methods more carefully account for the proper spectral shape associated with high-amplitude ground motions. To gauge prediction accuracy, the individual predictions are then compared to a "high-end prediction" which is based on a large number of structural analyses. The findings show that methods that account for appropriate spectral shape lead to accurate response predictions (over-prediction of 1% or 6%, depending on method) and the building code methods result in 30% to 60% over-prediction of response relative to the other methods.

Introduction to this Study and the PEER GMSM Program

Nonlinear dynamic analysis of structures is becoming increasingly prevalent in code and regulatory documents prescribing design and analysis. A recurring issue for both practicing engineers and developers of these documents is the selection and the scaling (or more generally the "modification") of ground motions for these nonlinear dynamic analyses. Nonlinear structural response is often highly sensitive to the selection and modification of input ground motions, so the choice of method is an important decision.

Many ground motion selection and modification methods have been proposed in the literature. One commonly used method is that prescribed by the ASCE7 Standard (ASCE, 2005). This paper will demonstrate that this prescriptive approach can lead to highly conservative over-prediction of structural response under extreme ground motions. For an engineer or researcher aiming to obtain an *accurate* (as opposed to a *conservative*) prediction of structural response, there is currently little impartial guidance regarding which methods are appropriate. This leaves the engineer or researcher with an important decision that is virtually uninformed.

To address this issue, the Pacific Earthquake Engineering Research (PEER) Center established the Ground Motion Selection and Modification (GMSM) Program, and this paper presents some of the initial findings and recommendations of this Program. The overall mission of the GMSM Program is to provide practical guidance and tools to the engineering community regarding ground motion selection and modification methods, while at the same time advancing the state of research in this area.

The PEER GMSM Program is nearly finished with a large study designed to provide guidance regarding which GMSM methods are appropriate for predicting median interstory drift response (PEER GMSM, 2008). The overall study includes evaluation of four buildings (4-, 12-, and 20-story reinforced concrete (RC) special moment resisting frames, and a 12-story RC shear wall), two ground motion scenarios, and five classes of GMSM methods. The purpose of this overall study is to provide the engineering community with a foundation, backed by comprehensive research, for choosing appropriate GMSM methods. The current study (outlined in this paper, and documented in detail in the forthcoming PEER report) should thus be considered as an initial building block towards future PEER GMSM studies that will grow increasingly more comprehensive.

This paper presents a brief overview of the approach taken in the overall PEER GMSM study, and then presents a subset of detailed results for the 20-story RC frame building. The results and comparisons presented in this paper are aimed at comparing building code based methods (ASCE7, 2005) with more advanced methods that account for the appropriate spectral shape of extreme ground motions. Accordingly, the classes of methods considered are (a) building code methods based on matching a uniform hazard spectrum or a code design spectrum, (b) methods that match the spectral shape associated with high-amplitude ground motions (using the Conditional Mean Spectrum), and (c) methods that use a proxy to account for appropriate spectral shape (e.g. methods that selection motions based on the ground motion parameter epsilon, ε, which is the number of logarithmic standard deviations that the observed Sa value is above the median expected from a ground motion prediction equation or GMPE). Using a total of ten GMSM methods from the above three categories, the median interstory drift response is predicted using set of seven ground motions (to be consistent with current building code requirements). These predictions are then compared against a "high-end prediction" to determine the prediction accuracy of each method; the approach to creating this "high-end prediction" is discussed later in this paper.

Structural Design and Structural Modeling

The aforementioned seismic response predictions are for a 20-story RC special moment perimeter frame structure, designed based on current building code requirements (ASCE, 2002; ACI, 2002). This structural design and analytical model was developed as part of both the ATC-63 project (ATC, 2008) and for a Ph.D. dissertation (Haselton and Deierlein, 2007). For reference purposes, this building is called design ID1020 in the cited references. As part of the ATC-63 project, a practicing engineer carefully reviewed the structural design, to ensure compliance with common design practice. The fundamental period of this 20-story building is 2.63 seconds, as estimated from eigenvalue analyses.

The structural model was created with the OpenSees structural analysis platform (OpenSees, 2007), using the element model recently developed by Ibarra, Medina, and Krawinkler (2005) and implemented into OpenSees by Altoontash (2004). Figure 1 shows the monotonic behavior and the cyclic behavior of the model. This model is capable of capturing the important behavior from yield up to collapse of the structure, specifically including both *in-cycle* strength degradation (which accounts for effects of rebar buckling and other modes of rapid strength loss, and is shown by the negative slope in Figure 1a) and *between-cycle*, or "*cyclic*" deterioration (the strength loss shown between cycles in Figure 1b).

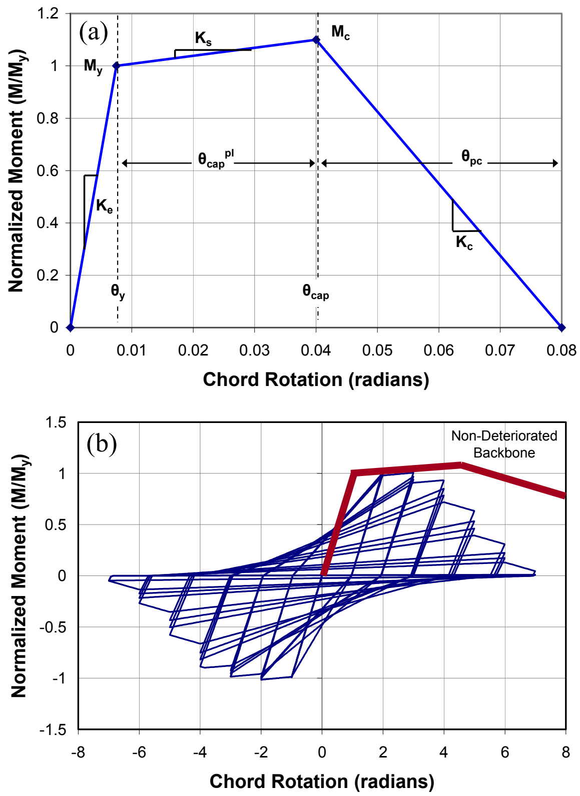


Figure 1. Monotonic and cyclic behavior of component model used in this study. The element model and hysteretic rules were developed by Ibarra, Medina, and Krawinkler. Figure after Haselton and Deierlein (2007, chapter 4).

The above model was calibrated to results of over 250 experimental tests to develop empirical equations relating the modeling parameters (e.g. strength, plastic rotation capacity, etc.) to the design parameters (e.g. axial load ratio, transverse reinforcement ratio, etc.) (Haselton and Liel et al., 2008).

Figure 2 shows the static pushover curve for this 20-story building. The lateral load distribution is based on the equivalent static procedure of ASCE7 (ASCE, 2005) and the static overstrength is 1.6 (the overstrength is relatively low, because this is a perimeter frame building, and lateral loads dominated the strength design). The structural model includes all appropriate P-Delta effects, as can be seen in the pushover curve by the slightly negative post-yield stiffness.

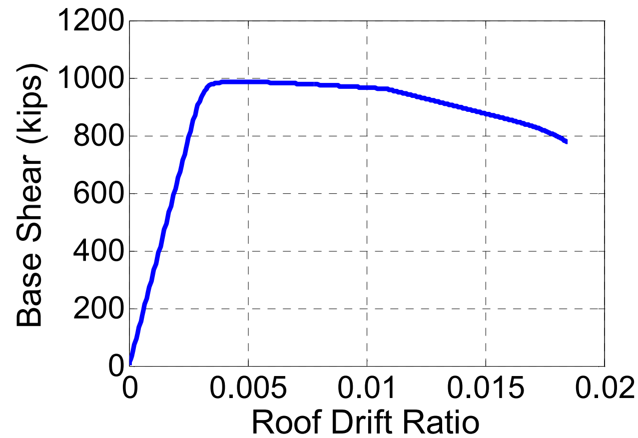


Figure 2. Static pushover curve of the 20-story reinforced concrete special moment frame building. The lateral load distribution is based on the equivalent static method of ASCE7 (ASCE, 2005).

The structural response of interest for the current study is the maximum inter-story drift ratio (MIDR). It is defined as the single maximum inter-story drift ratio value observed between any two floors during the time series analysis and is therefore not derived from any combination rules.

Methodology: Ground Motion Scenario

For purposes of selecting sets of ground motions and comparing the structural response predictions, a target ground motion scenario was developed. The scenario used in this study is for a magnitude 7.0 event occurring on a strike-slip fault, at a site that is 10 km from the fault rupture on soil with $V_{s,30}$ of 400 m/s (shear wave velocity for the top 30 m of the soil profile). The ground motion for this scenario is also constrained to provide a spectral acceleration at the building's first mode $Sa(T_1)$ that is two standard deviations above a median prediction (using the current Campbell and Bozorgnia 2008 GMPE model). This type of ground motion event is also often referred to as a "+2ε motion". For the 20-story building presented earlier, this ground motion corresponds a spectral acceleration demand of Sa(2.63s) = 0.402g. For easy comparison, this is equivalent to a demand at a 1.0 sec period, Sa(1.0s) of 1.05g.

The "+2ε" consideration reflects the fact that both probabilistic and deterministic ground motion analysis procedures generally result in target Sa values that are larger than the median Sa associated with the scenario magnitude and distance. In fact, this ground motion scenario was specifically chosen to be a rough upper bound on 2% in 50 year (or Maximum Considered Earthquake) ground motions at high seismic sites of California. Since typical high seismic sites in California, (not near field cases), exhibit predicted demands near Sa(1.0s) of 0.9g (on generic soil class D), which is slightly less extreme than the scenario considered here. Additionally, for a 2% in 50 year motion at such a site in California, the typical ε values are between 1.0 and 2.0 (ATC, 2008; Appendix B), so the selected scenario, with ε = 2.0, constitutes a rough upper bound. Note that the overall study (PEER GMSM, 2008) includes an additional ground motion scenario that constitutes a lower bound on 2% in 50 year motions at such sites (i.e. the second scenario has an ε = 1.0 and lower Sa demands).

Methodology: The High-End Prediction of Response

The important conclusions of this study rely on the comparison of response due to ground motions selected and modified using different methods. It was decided early on to develop a high-end response prediction which is expected to be close to the true structural response to be used as a point of comparison (POC). This allows the methods to be compared not only between them, but relative to the median POC, which is a necessary step to estimate bias.

The development of the POC prediction involved (a) selecting a large bin of records consistent with the M7, distance 10km ground motion scenario (98 in this case), (b) completing structural analyses using the set of records scaled by arbitrary factors of 1.0, 2.0, 4.0, and 8.0, (c) completing regression analysis (which is designed to remove the effect of scaling bias) to relate structural maximum interstory drift response to the important ground motion parameters (e.g. $Sa(T_1)$, $Sa(2T_1)$, etc.), and then (d) integrating the regression equation over the proper distributions of the ground motion parameters used in the regression model. Using this approach, the POC prediction for the maximum interstory drift ratio (MIDR) is 0.019 for this 20-story building.

More information about development of the POC prediction can be found in the report on this research study (PEER GMSM, 2008), and the background principles can be found in (Watson-Lamprey, 2007).

Structural Response: Building Code Methods

The building code methods presented in this section include two interpretations of the requirements of the ASCE7-05 provisions (ASCE, 2005). More variants and details are presented in the report. The first method (method 206) is a strict interpretation of ASCE7-05, enforcing the requirements to match the event magnitude, site-source distance, and faulting mechanism, as well as ensuring that the median spectrum exceed the target spectrum from $0.2T_1$ to $1.5T_1$. Using this method, four sets of seven records were selected and scaled. Figure 3 shows the scaled acceleration spectra of one of the sets of seven records, as well as the target uniform hazard spectrum for the ground motion scenario used in this study.

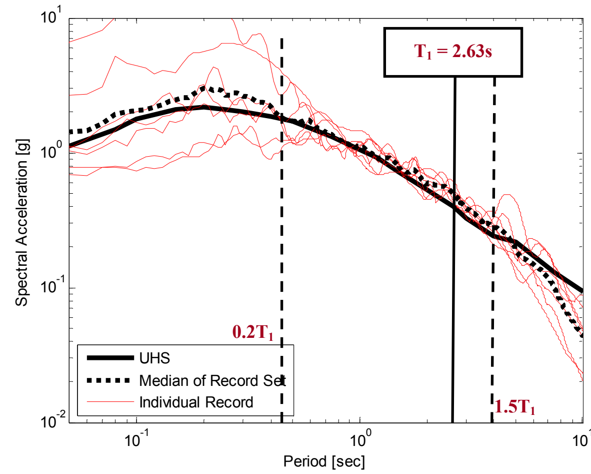


Figure 3. Scaled acceleration spectra for one set of seven records (set number two) selected using the strict interpretation of the building code methods.

The second variant on building code selection methods is one that really does not completely meet requirements of ASCE7-05, but is included here for comparison. This second variant (method 200) tries to *match* the uniform hazard spectrum (rather than *exceed* it), and makes no effort to match the event magnitude, site-source distance, or faulting mechanism (not shown here).

Four sets of seven ground motion records were selected for each of the two variants of the building code selection and scaling method for the 20-story building. Each record was used as input at the based of the model and the nonlinear dynamic structural analyses were completed to predict the MIDR. Table 1 shows the tabulated median MIDR values from each set of seven records. Figure 4 shows the individual response predictions from each record (blue dots) as well as the median values for each set (red crosses). Note that some records cause structural collapse (dynamic instability where drifts increase without bounds). This is indicated by a dot at the top of the figure, while the number in parenthesis shows how many records caused such structural collapse. Note also that although it is not a perfect measure in this case, the *counted* median was chosen because it allowed to compute a single MIDR value for each set. There is yet no consensus as to how to properly compute a mean or average that would account for the collapse cases.

Table 1.Median MIDR responses for sets of seven ground motions selected and scaled using building code methods (matching the uniform hazard spectrum).

Method Tag	Method Name	Set Index	Num. of Rec.	Individual Sets: Median MIDR	Individual Sets: Ratio to POC
206	Building Code - Strict ASCE7-05	1	7	0.0246	1.29
206	Building Code - Strict ASCE7-05	2	7	0.0341	1.79
206	Building Code - Strict ASCE7-05	3	7	0.0356	1.87
206	Building Code - Strict ASCE7-05	4	7	0.0262	1.38
200	Building Code - Relaxed Requirements	1	7	0.0200	1.05
200	Building Code - Relaxed Requirements	2	7	0.0224	1.18
200	Building Code - Relaxed Requirements	3	7	0.0379	1.99
200	Building Code - Relaxed Requirements	4	7	0.0281	1.48
			Median:	0.027	**1.43**
			Average:	0.026	1.36
			C.O.V.:	--	0.23
			Minimum:	0.017	0.91
			Maximum:	0.039	2.07

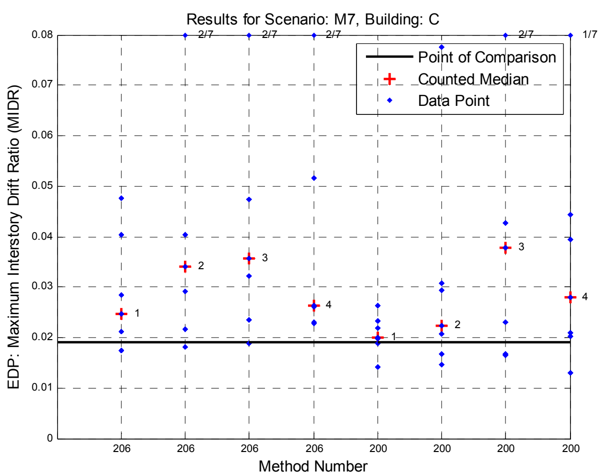


Figure 4. Maximum interstory drift ratio responses for sets of seven ground motion records selected and scaled using two methods consistent with the building code.

As compared to the POC prediction of 0.019, the records obtained using these two methods produce a median MIDR response that exceeds the POC by 43%. However, the second method (method 200) does not strictly comply with the requirements of the ASCE7-05 building code. If one strictly complies with all requirements (method 206), the median over-prediction is 59%, and if the requirements are loosened (method 200) then the over-prediction reduces to a median value of 33%. Note that these are a representative subset of results from the parent study (PEER GMSM, 2008) and more complete treatment of building-code based record selection methods can be found there.

In addition to the median predictions being large, the scatter leads to a wide range of individual predictions for these eight sets of records, from 5% to 99% above the POC. Figure 4 shows that for selection and scaling using these building code methods, there is an average of 1.1 building collapses for each set of seven records.

Structural Response: Conditional Mean Spectrum Methods

The reason that the building code methods lead to over-prediction of structural response relative to the POC is that the spectra are made to match to a uniform hazard spectrum, which simultaneously has large spectral acceleration demands at every period. Previous research has shown that this is not appropriate for rare ground motions in California (which have large positive ε values); a 2% in 50 year or a maximum considered earthquake (MCE) ground motion would be considered a rare ground motion. Such past research has shown that the spectral shape is much different than the shape of a code design spectrum or the shape of a uniform hazard spectrum (Baker, 2005; Baker and Cornell, 2006b). The expected spectra tend to have a "peak" with richer frequency content near the period used to define the ground motion intensity (typically the fundamental period of the building). Baker and Cornell (2006a) have recently published research that statistically defines the proper spectral shape for a given ground motion scenario and associated ε value; this spectrum has been termed a Conditional Mean Spectrum (CMS), as it is the *mean* response *spectrum* at all periods, *conditional* on knowledge of $Sa(T_1)$.

This section presents structural response predictions using four methods that match the CMS. Figure 5 shows the scaled acceleration spectra of one of the sets of seven records, and the target CMS for this ground motion scenario; the target CMS was developed in (Baker, 2006). For comparative purposes, the figure also shows the uniform hazard spectrum (which is the same as in Figure 3 and labeled as the median+2σ).

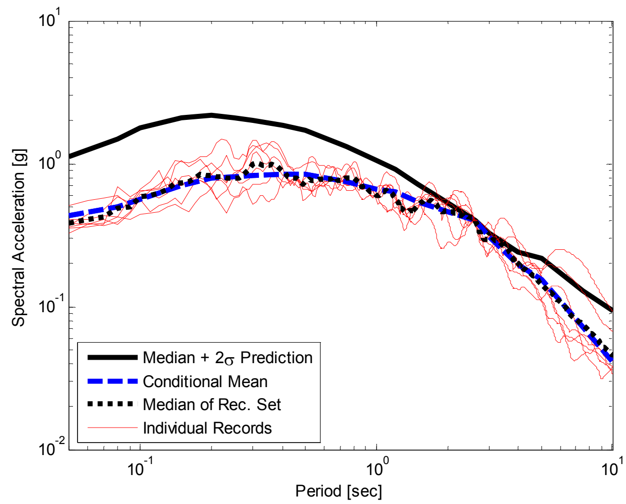


Figure 5. Scaled acceleration spectra for one set of seven records selected to match the conditional mean spectrum (method 300).

Figure 6 shows the individual response predictions from each record along with the median values for each set (not all methods have four corresponding sets). Note that none of the records selected to match the CMS caused structural collapse. Table 2 shows the tabulated median MIDR values from each set of records that were selected using methods that match the scenario CMS.

Table 2. Median MIDR responses for sets of seven ground motions selected and scaled using methods that match to the Conditional Mean Spectrum (CMS).

Method Tag	Method Name	Set Index	Num. of Rec.	Individual Sets: Median MIDR	Individual Sets: Ratio to POC
300	Conditional Mean Spectrum Selection with Scaling	1	7	0.0174	0.92
300	Conditional Mean Spectrum Selection with Scaling	2	7	0.0198	1.04
300	Conditional Mean Spectrum Selection with Scaling	3	7	0.0189	0.99
300	Conditional Mean Spectrum Selection with Scaling	4	7	0.0195	1.03
301	Genetic Algorithm Selection	1	7	0.0192	1.01
302	Semi-Automated Selection & Scaling	1	7	0.0172	0.91
302	Semi-Automated Selection & Scaling	2	7	0.0222	1.17
303	Design Ground Motion Library (DGML)	1	7	0.0180	0.95
303	Design Ground Motion Library (DGML)	2	7	0.0218	1.15
303	Design Ground Motion Library (DGML)	3	7	0.0203	1.07
303	Design Ground Motion Library (DGML)	4	7	0.0188	0.99
			Median:*	0.019	**1.01**
			Average:*	0.019	1.02
			C.O.V.:*	--	0.08
			Minimum:*	0.017	0.91
			Maximum:*	0.022	1.17

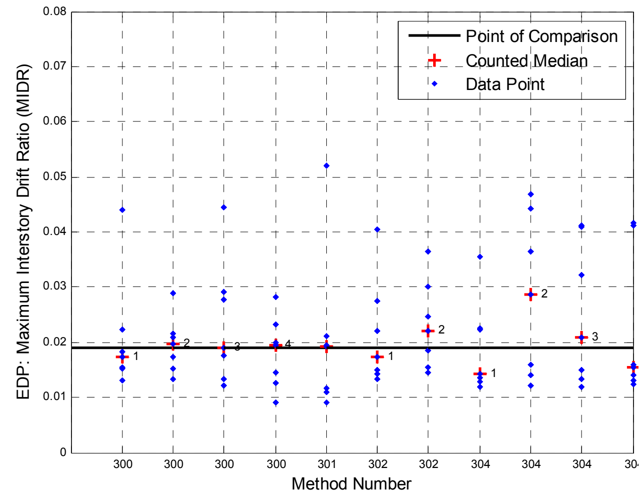


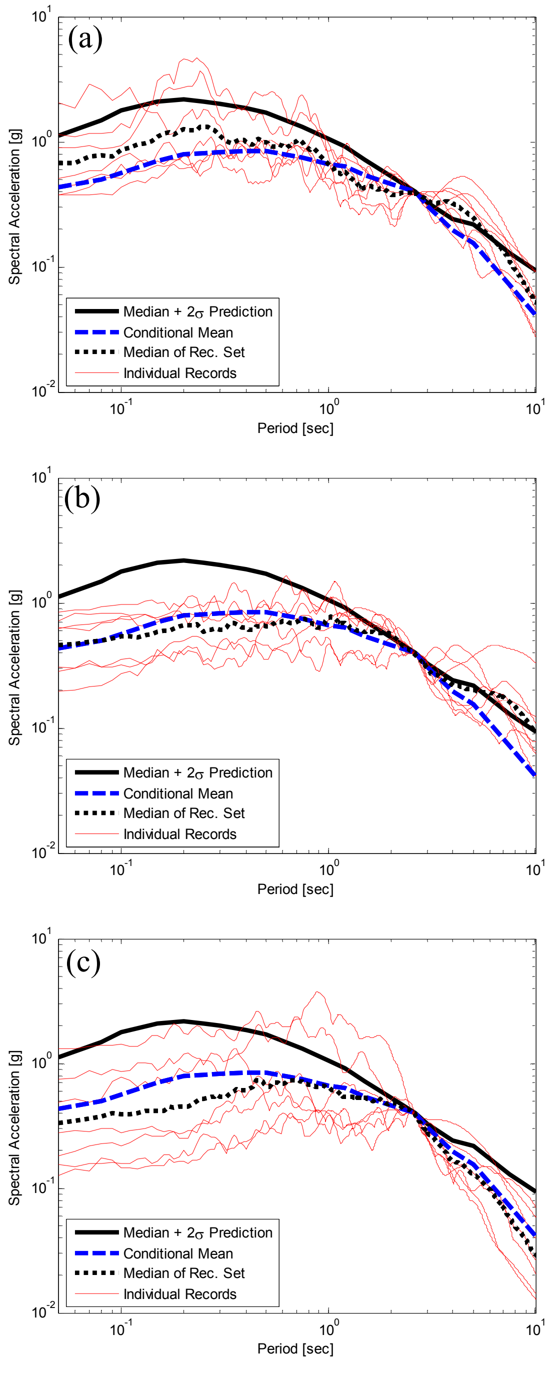
Figure 6. Maximum interstory drift ratio responses for sets of seven ground motions selected and scaled using methods that match to the Conditional Mean Spectrum (CMS).

These four CMS matching methods collectively have a median MIDR prediction of only 1% above the POC. Further inspection of each individual method shows that medians from each method also agree well, ranging only from 1% to 4% above the POC. Additionally, the values from each individual set of seven records fall in a relatively narrow range from 9% below to 17% above the POC. This shows good agreement between the POC predictions and predictions from CMS matching methods, because the CMS matching methods account for the peaked spectral shape that is statistically expected for an extreme ground motion (+2ε motion).

It should be noted that method 301 produces an accurate MIDR prediction for the 20-story building considered in this study, but it was not the case for other buildings considered in the parent study.

Structural Response: Methods that use a Proxy for the Conditional Mean Spectrum (ε)

Rather than matching directly to the shape of the CMS, the four methods of this group use the epsilon (ε) value of 2.0 as a proxy value to account for the CMS shape. This approach aims at selecting records that exhibit a +2 ε $Sa(T_1)$ value from a large database of records. The selected records tend match the CMS well *on average*, but the scatter is higher so the median spectra of small sets of records (e.g. sets of seven) can deviate substantially from the CMS. Figure 7 illustrates this phenomenon well by showing the spectra of each individual set of seven records selected using method 401, and Figure 8 shows the combined set of 28 records. It can be observed that the median of the combined set matches the CMS closely, but the median of each individual set can have substantial variability. The effects of this increased scatter is also observed in the structural response results, which are presented later in this section.



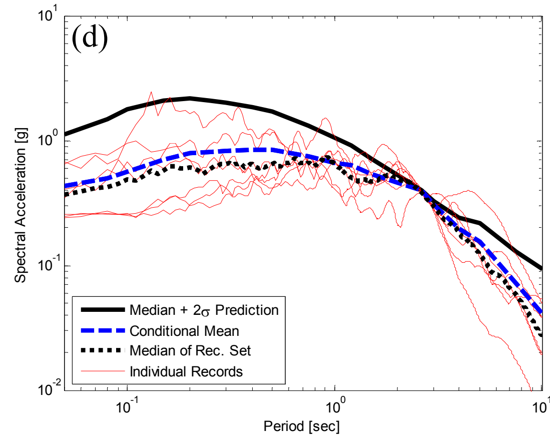


Figure 7. Scaled acceleration spectra for each individual set of seven records selected based on ε (from method 401).

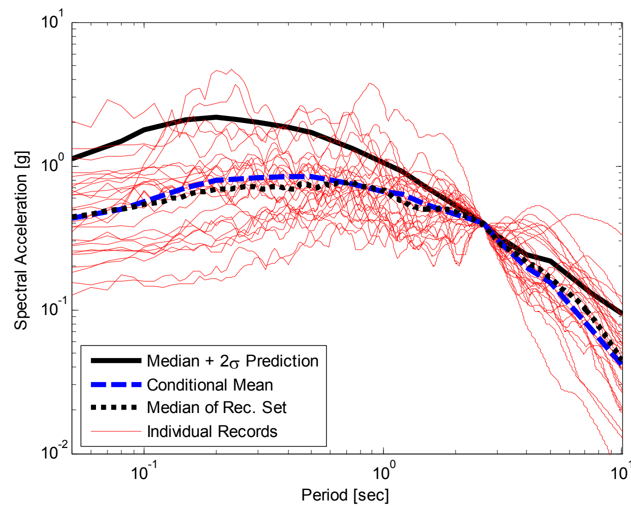


Figure 8. Scaled acceleration spectra for the combined set of 28 records selected based on ε (method 401).

Table 3 shows the tabulated median MIDR values from each set of seven records that were selected using the CMS Proxy (ε selection) methods. Figure 9 shows the individual response predictions from each record, as well as the median values.

Table 3. Median MIDR responses for sets of seven ground motions selected and scaled using CMS Proxy (ε selection) methods.

Method Tag	Method Name	Set Index	Num. of Rec.	Individual Sets: Median MIDR	Individual Sets: Ratio to POC
400	Target Spectrum Based on Epsilon Correlations	1	7	0.0230	1.21
400	Target Spectrum Based on Epsilon Correlations	2	7	0.0223	1.17
400	Target Spectrum Based on Epsilon Correlations	3	7	0.0219	1.15
400	Target Spectrum Based on Epsilon Correlations	4	7	0.0164	0.86
401	ε Selection with $S_{de}(T_1)$ Scaling	1	7	0.0357	1.88
401	ε Selection with $S_{de}(T_1)$ Scaling	2	7	0.0322	1.69
401	ε Selection with $S_{de}(T_1)$ Scaling	3	7	0.0151	0.79
401	ε Selection with $S_{de}(T_1)$ Scaling	4	7	0.0178	0.94
402	ATC-63 Method Applied to MIDR - Far-Field Set	1	44	0.0153	0.81
403	ATC-63 Method Applied to MIDR - Near-Field Set	1	56	0.0182	0.96
		Median:		0.020	**1.06**
		Average:		0.022	1.15
		C.O.V.:		--	0.32
		Minimum:		0.015	0.79
		Maximum:		0.036	1.88

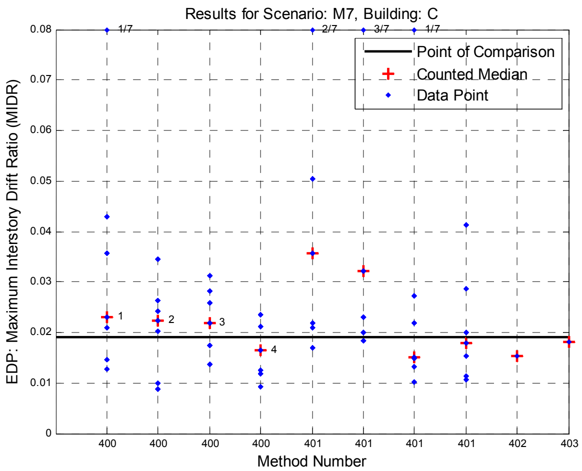


Figure 9. Maximum interstory drift ratio responses for sets of seven ground motions selected and scaled using CMS Proxy (ε selection) methods.

These four CMS Proxy methods collectively have a median MIDR prediction of only 6% above the POC, though the scatter in prediction is higher between the median predictions from each of the four methods (this is consistent with the scatter observed in the spectral shapes, Figure 7). Method 400 results in a median prediction of 16% above the POC, method 401 is 33% above the POC, method 402 is 19% below the POC, and method 403 is 4% below the POC.

It should be clearly stated that the "ATC-63" methods (402 and 403) do not strictly use the procedure proposed in the ATC-63 90% draft report, since ATC-63 is limited to collapse assessment and this study is focused on prediction on MIDR. Rather, these "ATC-63" methods use the same procedure that was used to *develop* the ATC-63 method. This is documented in Appendix B of the ATC-63 draft report (ATC, 2008), as well by Haselton and Deierlein (2007; chapter 3).

Summary and Conclusions

This paper presented an evaluation of the following three classes of methods.

- Building Code (methods which match the code design spectrum, or uniform hazard spectrum) [2 methods]
- CMS Matching (methods which match the Conditional Mean Spectrum) [4 methods]
- Proxy for CMS (method which match the ε value, as a proxy for the CMS spectral shape) [4 methods]

Table 4 presents the overall predictions by method class. These results can be summarized as follows:

- Building Code methods:
  - o Predictions are not accurate; the median over-prediction is 43%. This over-prediction is larger if the building code requirements are strictly imposed.
  - o Large variability in predictions between individual sets of seven records (5% to 99 over-prediction).
- CMS Matching methods:
  - o Predictions are accurate within 1% of the POC.
  - o Small variability in predictions between individual sets of seven records.
- Proxy for CMS methods:
  - o Predictions are accurate, on average, within 6% of the POC.
  - o There is non-negligible variability in the median predictions between each of the four methods.
  - o Large variability in predictions between individual sets of seven records (21% under-prediction to 88% over-prediction).

Table 4. Summary of response estimation bias factors by method class.

MIDR/POC	Building Code	CMS Matching	Proxy (i.e. ε)
Median:	**1.43**	**1.01**	**1.06**
Average:	1.51	1.02	1.15
C.O.V.:	0.28	0.08	0.32
Minimum:	1.05	0.91	0.79
Maximum:	1.99	1.17	1.88

Based on the results of this paper, and the previously published results on this same topic (Goulet et al. 2008), the following conclusions can be drawn regarding prediction of MIDR for structures subjected to an extreme ground motion (ε = 2.0 in this case). These results are for a single building, and are still considered preliminary until the full study is completed (PEER GMSM, 2008); the full study considers additional buildings, additional ground motion scenarios, and additional GMSM selection methods.

- If accurate predictions are desired, do not use building code methods. These methods lead to over-prediction of response because they match to the code design spectrum or the uniform hazard spectrum. Because the UHS by definition corresponds to +2 ε spectral accelerations at all periods, it is significantly richer in larger period spectral acceleration than realistic ground motions. As nonlinearity develops in the structure and the natural period lengthens, the structure is subjected to larger than expected ground motions. The shape of this spectrum is inappropriate for extreme (large positive ε) motions such as a 2% in 50 year or MCE motion in high seismic regions of California.
- If accurate predictions are desired, either:
  - Use a CMS matching method (method 300, 302, or 303), if a consistently accurate prediction of median MIDR is desired.
  - Use a Proxy for CMS (ε selection) method, if more variability in response is acceptable.

It should be emphasized that claiming that a method is "accurate" implies an ability to obtain an MIDR estimate (using a small number of records) that is consistent with a "true" MIDR for a ground motion scenario (in this case, estimated using a much larger number of ground motions and the "POC" approach described above). The target ground motion scenario consists of a magnitude 7.0 event occurring on a strike-slip fault 10km from the site, with an Sa(2.63s) value of 0.402g (2 standard deviations larger than the median predicted Sa(2.63s) value for this event). Note that this target ground motion scenario is not a UHS, because a UHS conservatively assumes extreme spectral amplitudes at all periods simultaneously—an outcome not observed in reality (and also not implied to occur by the seismic hazard analysis used to compute a UHS). This is the reason that the Code Methods, which are based on conservative UHS targets, produce conservative estimates of MIDR.

Future Research

This paper presented comparison of three classes of ground motion selection and modification (GMSM) methods for predicting the maximum inter-story drift ratio (MIDR) response of a 20-story RC frame building. The parent study is nearly complete to expand on this paper to include a total of four structures, five classes of GMSM methods (more than 25 method variants), and two ground motion scenarios. The results of this study will provide more generalizeable conclusions regarding GMSM methods for prediction of median MIDR response of modern buildings.

Regarding the specific topic of this paper, and in addition to completing the above mentioned study, the GMSM Program is considering extending this research in the following ways:

- Building code methods – Consider a more complete set of variations in how the building code methods can be interpreted and applied. Use this to determine which interpretations and decisions have important effects on the structural response predictions.
- Full distribution of response – This study was limited to prediction of median MIDR response, but the goal is to extend this study to investigate also predicting the variability of response.
- Other structural response parameters – This study was limited to predicting MIDR. A goal is to extend this study to investigate prediction of other important structural responses, such as peak floor accelerations (and base shear) and element plastic rotations.

On a more general level, the GMSM Program is working to develop new research avenues in the following directions (this is not an exhaustive list):

- GMSM methods for structural collapse assessment.
- GMSM methods for site response analyses.
- GMSM methods for seismic response of bridge structures.
- GMSM methods for nuclear structures.
- Evaluation of spectrum compatible GMSM methods.
- Evaluation of methods using synthetic records.
- GMSM methods and procedures for predicting an annual rate of structural response, or a complete structural response hazard curve.

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