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INFLUENCE OF GROUND MOTION SELECTION ON THE ASSESSMENT OF STEEL SPECIAL MOMENT FRAMES

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Abstract

This paper quantifies the impact of using different ground motion selection methods to evaluate the seismic performance of steel special moment frames. Two methods are investigated: a "traditional" approach, herein referred to as the Pacific Earthquake Engineering Research (PEER) method, and a newer approach known as the conditional mean spectrum (CMS) method. Amongst other differences, the PEER method uses the risk-based maximum considered earthquake (MCE_R) as the target spectrum, while the CMS method uses the conditional mean spectrum. Two special moment frames (4- and 8-story) designed in accordance with ASCE/SEI 7-10, are used to represent archetype steel frame buildings on the West Coast of the United States. The seismic performance of these frames are assessed with the nonlinear dynamic procedure prescribed in ASCE/SEI 41-13, using ground motions selected and scaled in accordance with both methods. The performance of the buildings is evaluated at the Collapse Prevention (CP) performance level for a far-field site located in Los Angeles, CA. The two ground motion selection methods lead to different structural response predictions, where the ground motions selected and scaled using CMS can result in a smaller dispersion of the output parameters. These results provide motivation for building standards, such as ASCE/SEI 41, to advocate implementing the CMS method as an alternative ground motions selection approach. The results also shed light on the influence of the ground motion selection method in the design of new buildings using the performance-based seismic design methodology.

Keywords: ground motion selection; conditional mean spectra; steel moment frame; seismic assessment

1. Introduction

Nonlinear dynamic analysis has become more popular among practitioners, mainly due to advancements in simulation and computational capabilities, as well as the increasing use of performance-based seismic design approaches. One of the main steps in assessing the response of a building using nonlinear dynamic procedures is to analyze the building model using a suite of ground motions. Several ground motion selection methods have been developed that vary in terms of the selection criteria, error computation, target spectrum, etc. The premise of all ground motion selection methods is to select records that reasonably estimate ground motions for a specific building site anticipated to occur in a future earthquake. The use of different ground motion selection method leads to different nonlinear response.

In general, ground motion selection and scaling methods can be categorized as either a) amplitude scaling, or b) spectral matching (*i.e.*, modification of frequency content). This paper focuses on methods in the former category. A comprehensive list of approaches to select and scale the ground motions are reported in [1]. Typical spectra used as targets are the MCE_R spectrum, which is developed using parameters from ASCE/SEI 7-10 [2] (referred to as ASCE 7), or the Uniform Hazard Spectrum (UHS), which is constructed from hazard curves from Probabilistic Seismic Hazard Analyses. These selection methods often choose the ground motions that best match the target spectrum after they have been scaled. The basis for selecting the best match is to minimize the error between the target spectrum and the selected ground motion. However, both the error and the target spectrum can be calculated in different ways, potentially leading to significantly different results.

This study focuses on two ground motion selection methods: 1) the Pacific Earthquake Engineering Research (PEER) method, which can be considered a well-established method widely used in research and practice; and 2) the conditional mean spectrum (CMS) method, a newer method that has been employed more in research. In the PEER method, ground motions are selected to minimize the error between each ground motion spectrum and the target spectrum, MCE_R in this study, across a range of periods. The approach is referred to as the PEER method because it is implemented in the PEER online tool. In contrast, the CMS method uses the conditional mean spectrum as the target for matching ground motions and scaling them to match spectral acceleration (S_a) at a conditioning period.

To investigate the effects of these ground motion selection methods, newly designed 4- and 8-story buildings are assessed at the Collapse Prevention performance level using the nonlinear dynamic procedure outlined in ASCE/SEI 41-13 [3] (referred to as ASCE 41) for ground motions selected using the CMS and PEER methods. The predicted performance of the buildings, in terms of nonlinear hinge deformations and their corresponding dispersion, is compared for the two selection methods.

2. Background on Ground Motion Selection and Scaling Methods

2.1 Conditional Mean Spectrum

The CMS method is a site-specific ground motion selection method in which scaled ground motion records are selected based on how closely they match a conditional mean target spectrum across a range of vibrational periods [4]. The CMS was developed as an alternative to the conservative UHS. The UHS is constructed from spectral acceleration values of hazard curves developed using probabilistic seismic hazard analysis at a selected probability of exceedance (e.g., 2 % in 50 years) with every value of the UHS having the same exceedance probability. The CMS is a more realistic target for selecting and scaling ground motions, because of the UHS intrinsic conservatism due to the unlikely scenario of all the spectral accelerations occurring in a single event [4]. Instead, the CMS is conditioned, or anchored, to a single spectral acceleration at a period of significance, such as the building's fundamental period.

In this study, the risk-targeted maximum considered earthquake (MCE_R) is selected as the spectrum to anchor the CMS. Once the spectral acceleration at the conditioning period (T^*), *i.e.* the period in which the spectral acceleration of the CMS matches the MCE_R is determined, the rest of the CMS spectrum, at each given period (T_i), is computed per Equation (1) [4].

$$\mu_{lnSa(T_i)|lnSa(T^*)} = \mu_{lnSa}(M,R,T_i) + \rho(T_i,T^*)\varepsilon(T^*)\sigma_{lnSa}(M,T_i) \tag{1}$$

Where $\mu_{lnSa(T_i)|lnSa(T^*)}$ is the logarithmic mean Sa at period T_i, at a given Sa at period T^*, $\mu_{lnSa}(M,R,T_i)$ is the logarithmic mean of Sa from the GMPM [5], M and R are the earthquake mean magnitude and mean distance from deaggregation, respectively [4,6], $\rho(T_i,T^*)$ is the correlation coefficient between ε at T_i and T^*, $\varepsilon(T^*)$ represents the number of standard deviations the target spectral acceleration differs from the median ground motion at the conditioning period [4], and $\sigma_{lnSa}(M,T_i)$ is the logarithmic standard deviation of Sa from the GMPM. Additional information regarding the calculation of the CMS target spectrum is provided in [7]. The computed CMS has lower spectral accelerations than the MCE_R spectrum, with the exception of the acceleration at the conditioning period, which matches the MCE_R, as shown in Fig. 1. This implies that if a structure is subjected to ground motions matched to the CMS, better performance is expected.

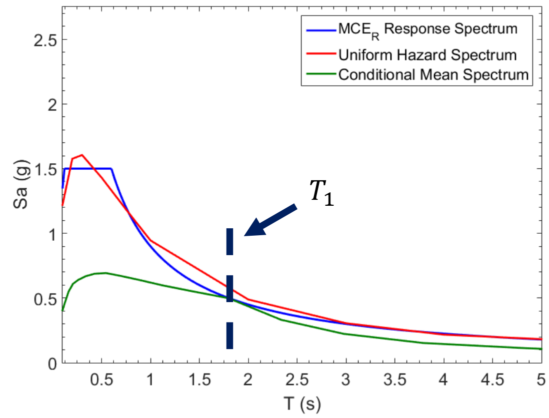


Fig. 1 – Comparison of the UHS, MCE_R spectrum, and CMS conditioned at T_1 = 1.81s for the 4-story SMF.

Once the CMS spectrum is developed, the ground motions are selected based on how similar their response spectrum is compared to the CMS. The similarity is based on the smallest sum of squared errors (SSE) as defined in Eq. (2) [4]:

$$SSE = \sum_{i=1}^{n} \left(\ln Sa(T_i) - \ln Sa^{CMS}(T_i)\right)^2 \tag{2}$$

where $\ln Sa(T_i)$ is the log spectral acceleration of individual records at period T_i, $\ln Sa^{CMS}(T_i)$ is the log CMS spectral acceleration at period T_i. The upper limit n in the summation refers to the number of partitions of the period interval of interest. Ground motions can also be selected to match the variance, σ, of the CMS spectrum computed from a ground motion prediction model, *i.e.* the conditional spectra (CS) method; but it should be noted that the CMS method does not consider minimizing the error of the variance [4]. In this method, the ground motions are scaled to match the MCE_R at the conditioning period and then selected based on least error.

2.2 PEER Method

The second approach used in this study involves scaling ground motions to minimize the error between each ground motion spectrum and the target spectrum, MCE_R, across a range of periods. The difference between the target spectrum and each individual spectrum is defined as an error, and computed using the mean squared error (MSE) as defined in Eq. (3):

$$MSE = \frac{\sum_i w(T_i)\{\ln[Sa^{target}(T_i)] - \ln[f * Sa^{record}(T_i)]\}^2}{\sum_i w(T_i)} \tag{3}$$

where $w(T_i)$ is the weight assigned to a desired period, T_i; S_a^{target} is the target spectral acceleration; S_a^{record} is the individual record spectral acceleration; and f is a scale factor. In this study, w is set to 1.0 across the period range of $0.2T_1$ and $2T_1$. The smaller the error, the better the ground motion produces a response spectrum that matches the target spectrum.

3. Archetype Building

3.1 Design and Configuration

Two archetype buildings (4- and 8-stories) are investigated in this paper. The buildings are designed in accordance with the 2012 International Building Code (IBC) [8], and its referenced standards (*i.e.*, ASCE 7 and AISC 341-10 [9]). The seismic force-resisting system (SFRS) is an exterior three-bay special moment frame (SMF) in the east-west direction and an exterior two-bay special concentrically braced frame (SCBF) in the north-south direction. This paper focuses only on the SMF performance. Fig. 2(a) and (b) show the building floor plan and SMF elevations, respectively. Reduced-beam-sections (RBSs) are used for the SMF beam-to-column connections, and columns are sized to satisfy strong-column/weak-beam requirements. Additionally, columns are upsized where necessary to avoid the use of doubler plates to strength the column webs. Detailed information regarding building properties, materials, and the design process can be found in Harris and Speicher [10].

The building is assumed to be located on a site with stiff soil (Site Class D), and is assigned to Seismic Design Category D with spectral accelerations S_S = 1.5 g at T_s = 0.2 s., and S_1 = 0.59 g at T_1 = 1.0 s. The equivalent lateral force (ELF) procedure of ASCE 7-10 is used to determine the seismic design loads. The frames are also designed to resist wind loads, in which the basic wind speeds are set to 177 km / h (110 mph) for the 700-year (strength) and 116 km / h (72 mph) for the 10-year wind (drift).

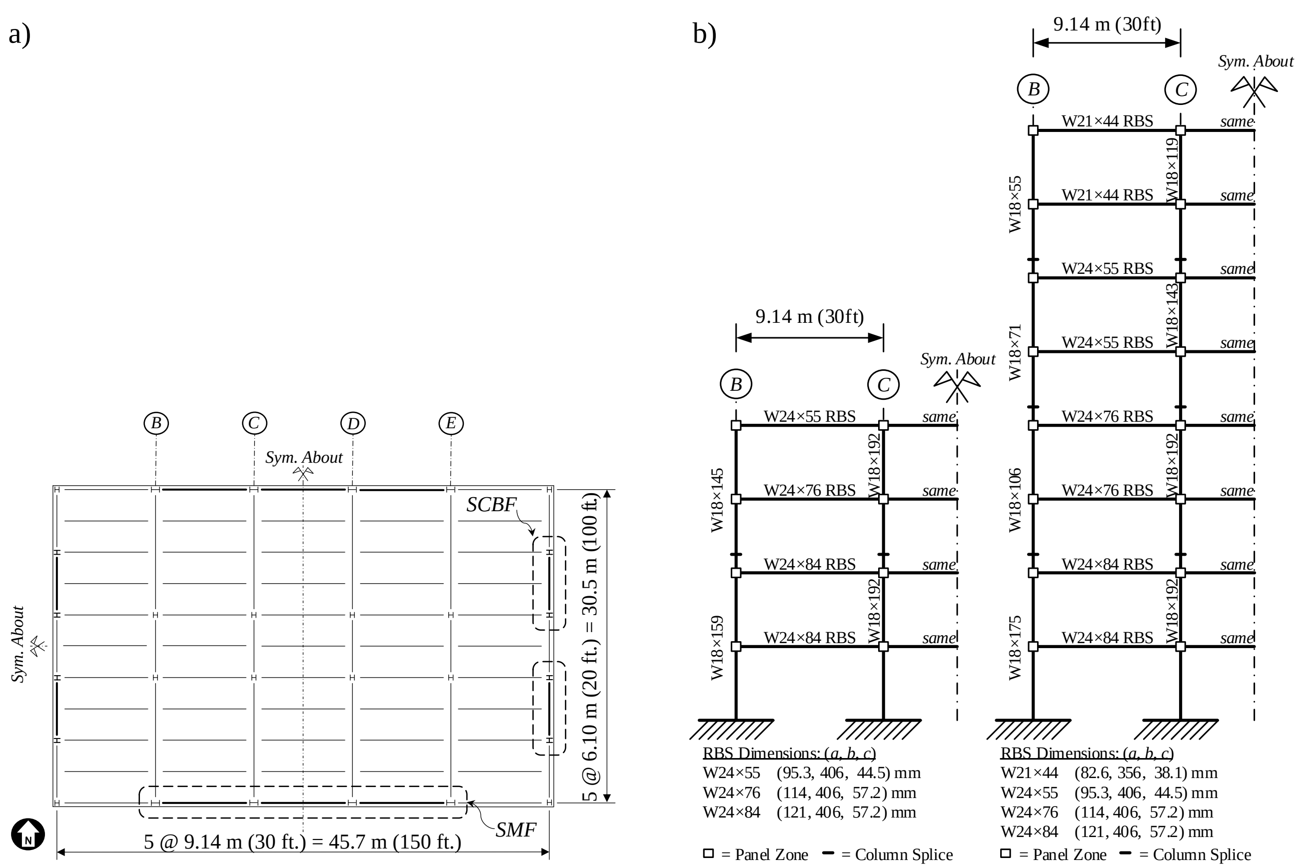


Fig. 2 – (a) Floor plan and (b) SMF elevations for the archetype buildings used in this study.

4. Site Selection

The archetype building is considered to be located in the city of Los Angeles, CA., a region with a high seismic hazard level. A far-field site within Los Angeles area is selected based on the soil classification and the mean rupture distance. The soil type was selected to match the site class for which the archetype building is designed for NEHRP soil type D with an average shear wave velocity (V_{s30}) of 180 m/s to 360 m/s [11]. The selected site has a V_{s30} value of 300 m/s to 360 m/s. The site was selected to satisfy the ASCE 7 requirements for a far-field site. According to ASCE 7 a site is considered far-field if it is located more than 15 km (9.3 miles) from a rupture plane. The information on the R_{rup} of the site was computed using the USGS's deaggregation online tool [11]. The selected far-field site (latitude/longitude = 34.197/-118.645) has a mean rupture distance of 17.2 km, according to the deaggregation computed with the USGS tool.

5. Implementation of the Ground Motion Selection

5.1 General Criteria for Ground Motion Selection

The criteria for the selection and scaling of ground motions meet or exceed ASCE 7 requirements, and include the following steps for the two methods investigated:

1. Fourteen ground motions records are selected (ASCE 7-16 requires 11 records)
2. The scale factor on individual record is no greater than 2.5 (ASCE 7-16 limits the scale factor to 4.0)
3. No more than one record is selected from a recording station
4. No more than three records are selected from the same event

A set of ground motion selection recommendations are adopted from ASCE 7-16 [12], as ASCE 7-16 is the first ASCE 7 standard that includes guidelines on the use of the CMS method. Criteria beyond the above requirements are described in the following sections specific to the two selection methods.

5.2 Implementation of Conditional Mean Spectrum Ground Motion Selection

The first step in implementing the CMS method is to choose the conditioning periods. In addition to the fundamental period of the system, T_1, multiple periods are used as conditioning periods to account for different structural performance aspects [13]. A short period is used to account for the higher mode contributions, while a long period is used to account for the effects of period elongation [7]. This study follows the suggestions of ASCE/SEI 7 that recommends using a lower limit of no more than $0.2T_1$ and an upper limit of no less than $2T_1$ for the bounds of the period range. Then, periods of $0.2T_1, T_1$, and $2T_1$ are initially selected as the conditioning periods. A fourth conditioning period of $0.4T_1$ is added to satisfy the requirement of having the envelope of the target spectra exceed 75% of the MCE_R between $0.2T_1$ and $2T_1$.

Ground motions are selected following the procedure developed by Jayaram et al. [14]. The procedure constructs the CMS based on the structural properties and hazard deaggregation, and selects a set of ground motions from the PEER NGA-West2 ground motion database [15] with the least amount of error (SSE) with respect to the target spectrum. The scale factor for each ground motion is determined by dividing the spectral acceleration value of the CMS at the conditioning period by the acceleration value of the selected ground motion at the same period. This method of scaling ensures that every selected ground motion, for a given target spectrum, has the same S_a at the conditioning period, creating a "pinch point". Fig. 3(a) shows the 14 ground motions selected using the CMS method for the 4-story building conditioned at the fundamental period, T_1. Fig. 3(b) presents the target and the average mean spectra for the four conditioning periods used in this study (i.e, $0.2T_1, 0.4T_1, T_1$, and $2T_1$). The 4- and 8-story frames are evaluated for four ground motion sets selected, one at each of the conditioning periods, to identify the maximum mean demand.

5.3 Implementation of PEER Ground Motion Selection

The PEER NGA-West2 database tool [15] is used to select ground motions based on minimizing the error (MSE) across a period range of $0.2T_1$ and $2T_1$. The desirable rupture distance is selected between 10 and 30 km; the shear wave velocity (V_{s30}) is chosen between 300 m/s and 360 m/s. No restriction is employed on the fault type or shape of the ground motion. A uniform weighting of spectral acceleration (i.e., $w = 1.0$ in Eq. 3) is considered for computing the error at various periods in the range of interest. Ground motions are selected independent of component direction, and the 14 scaled records with the minimum MSE are selected with the condition that no two records are from the same station. The selected ground motions are scaled using a suite scale factor, to ensure that the arithmetic mean of the selected ground motions does not drop below the target spectrum between $0.2T_1$ and $2T_1$, as suggested by ASCE 7-16. In the PEER ground motion selection method, the maximum scale factor for *individual* ground motions is set as 2.5. However, this limit may be exceeded when the arithmetic mean spectrum of the individual records is scaled to ensure the mean spectrum is larger or equal than the target spectrum. Note that even in this case, the scale factor is still less than four, as recommended by ASCE 7-16. Fig. 3(b) shows the average of 14 ground motions selected using the PEER method for the 4-story building. The average acceleration of the PEER ground motion records is higher than that of the CMS records between $0.2T_1$ and $2T_1$. This difference implies that the PEER ground motions may lead to larger inelastic building responses than from the CMS records.

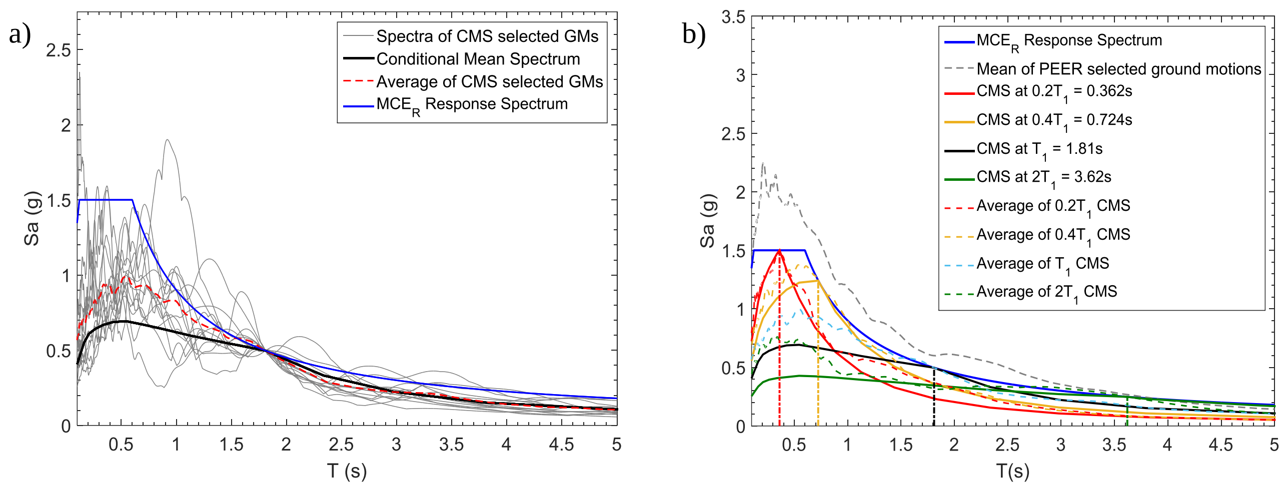


Fig. 3 – (a) Response spectra of ground motions for the 4-story building selected using the CMS method conditioned at $T_1 = 1.81$ s (b) the target and average CMS spectra for four conditioning periods in comparison with the average of the PEER spectra for the 4-story building.

6. Assessment of Moment Frames

An ASCE 41 seismic performance assessment using the nonlinear dynamic procedure is conducted in this study. The structural performance is evaluated at the Collapse Prevention level. The following sections give a brief description of the nonlinear model and then present the results. Additional details on carrying out the ASCE 41 assessment on these archetype buildings can be found in Harris and Speicher [10].

6.1 Overview of Perform 3D Model

The buildings are modeled in three dimensions using PERFORM-3D [16]. For the gravity framing system, the beams and columns are modeled with elastic elements, and the beam-to-column connections as pinned. For the SFRS, each potential nonlinear action is identified and modeled with a discrete nonlinear element. The nonlinear behavior of the beams is modeled with moment-curvature hinges that are placed at the centerline of each RBS. The reduced stiffness of the RBS is captured by using a prismatic section over the entire length of the RBS with cross-sectional properties equal to those at the ends of the center two-thirds of the RBS. The nonlinear behavior of the columns is modeled with moment-curvature hinges that vary based on axial load. These column hinges are placed at a distance of half the column depth away from the face of the beam. The column base is modeled as fixed. Lastly, the nonlinear behavior in the panel zones is modeled with PERFORM-3D'S panel zone element, which is based on the Krawinkler model [17]. Each of these nonlinear models is initially constructed using ASCE 41 modeling parameters defined in ASCE 41 Table 9-6 and then qualitatively calibrated against experimental tests.

The nonlinear analysis is set to terminate when the solution fails to converge or when an arbitrary roof drift ratio of 20 percent is reached. Collapse modes not modeled herein (e.g., failures in the gravity framing system) would likely occur well before 20 percent is reached. The impact of the modeling uncertainty [18] is not considered in this study.6.2 Nonlinear Dynamic Procedure Results

6.2.1 Format for Results Presentation

In this paper the results are presented in terms of a *normalized* demand-capacity ratio, DCR_N (the *N* subscript is added to distinguish it from the *DCR* defined in ASCE 41 §7.3.1.1, which is the unreduced demand-capacity ratio in a linear analysis). A DCR_N value greater than unity indicates that a component does not satisfy the acceptance criteria. The DCR_N is defined as shown in Eq. (4) and Eq. (5) [10]:

$$\textit{Deformation-controlled}: \quad DCR_N = \frac{\theta_{total}}{\kappa(\theta_y+\theta_{pe}+\theta_{p,AC})} \tag{4}$$

$$\textit{Force-controlled}: \quad DCR_N = \frac{\theta_{total}}{\kappa\theta_y} \tag{5}$$

where $\theta_{plastic}$ is the plastic deformation, $\theta_{elastic}$ is the elastic deformation, θ_y is the yield deformation, θ_{pe} is the post-yield elastic deformation, θ_{total} is the total deformation, and $\theta_{p,AC}$ is the acceptance criterion based on plastic deformation defined in ASCE 41. The Collapse Prevention acceptance criterion is used for the $\theta_{p,AC}$ parameter.

ASCE 41, Chapter 9 defines which actions are force versus deformation-controlled in a SMF. In general, a component is considered deformation-controlled if inelastic action is expected and the component exhibits ductile behavior. In contrast, a component is considered force-controlled if inelastic action is not desired or if the component exhibits non-ductile behavior. Beam-to-column connections and panel zone rotations are generally considered deformation-controlled, while column rotations classification depends on the level of axial load. The axial deformations in columns are always considered force-controlled.

6.2.2 Central Measure of Dispersion using ASCE 41 Approach

In this section the DCR_N plots for nonlinear dynamic analysis of the 4- and 8-story moment frames are presented for the mean and median response of the RBS components, assuming DCR_N results can be characterized with a normal (Gaussian) distribution. In calculation of the mean and median, all analysis results including the collapsed cases identified by an upper roof drift limit of 20 % are used. Fig. 4(a) shows the DCR_N values for the RBS hinges of the 4-story building over the height using the PEER and CMS methods. The presented DCR_N values of the CMS selected ground motions are the ones obtained for the controlling period (*i.e.*, the controlling period from the analysis that produced the largest mean DCR_N). The results presented in Fig. 4(a) show that the CMS method provides lower mean and median DCR_N than those obtained from the PEER method at every floor level, with the maximum difference of about 55 % in mean and median between the two methods. Fig. 4(a) also shows that the RBS connections do not pass the ASCE 41 acceptance criteria, *i.e.* the mean DCR_N value is greater than 1.0, when PEER method ground motions are employed. Conversely, the same components show satisfactory performance when CMS method ground motions are used. Note that the mean is obtained assuming a normal (Gaussian) distribution. More important, some of the 14 realizations may collapse, and in these cases an upper roof drift limit of 20 % was used in the calculations.

The results of the 8-story building are similar to those of the 4-story building with the CMS selected ground motions providing lower DCR_N values than those from the PEER method. For the 8-story RBS components, the CMS mean is lower than the PEER mean with a maximum mean difference of 70 %, and a maximum median difference of 55 %, as shown in Fig. 4(b). A comparison of the 4- and 8-story results shows an increase in the percentage difference in the predicted mean response as the building height increases. However, the difference in the median response does not vary by the number of stories. The larger difference in the mean response of the 8-story building, in comparison to the 4-story building, occurs because more analysis cases reach the 20 % drift limit for the PEER records. This indicates that the average response may not be the best representative of the structural response, as it will depend highly on the assumptions used in the analysis stage, such as the maximum allowable interstory drift before collapse. The median, on the other hand, is a more stable central measure of dispersion because it does not depend on the assumed probabilistic distribution function.

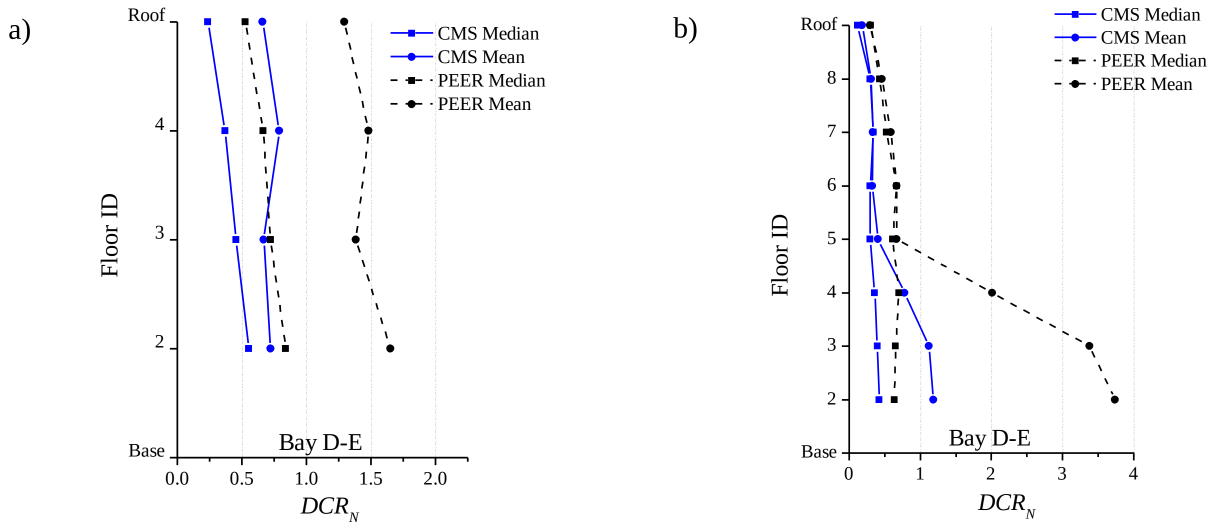


Fig. 4 – Comparison of max DCR_N values of the reduced beam section for the (a) 4-story and (b) the 8-story buildings computed for ground motions selected using the CMS and PEER methods

6.2.3 Central Measure of Dispersion using a Lognormal Distribution

A series of Kolmogorov-Smirnov tests on the DCR_N data demonstrated that the lognormal distribution fits the data more appropriately than a normal distribution. This is an expected result given that the data has only positive values, and it is skewed to the right end of the distribution [19]. Based on this outcome, the DCR_N statistical output parameters are computed in this section using a lognormal distribution. For this distribution, the mean of the data can be computed by Equation (6) [20]:

$$\mu = e^{\bar{u}_{lnx}} * e^{\frac{\sigma_{lnx}^2}{2}} = \bar{\mu} * e^{\frac{\sigma_{lnx}^2}{2}} \qquad (6)$$

Where $\bar{u}_{lnx}$ is the mean of the natural logarithm of DCR_N values, $\bar{\mu}$ is the median of the data, and σ_{lnx} is the standard deviation of the natural logarithm of DCR_N values, which can be computed by Equation (7) [21]:

$$\sigma_{lnx} = \ln\left(\sqrt{\frac{84^{th}}{16^{th}}}\right) \qquad (7)$$

where 84^{th} and 16^{th} represent the 84^{th} and 16^{th} percentile of the 14 DCR_N values for each element, respectively. Note that σ_{lnx} and μ are computed in such a way that collapse of a couple of realizations does not force to the use of the arbitrary roof drift limits. Fig. 5(a) and Fig. 5(b) plot the mean and median response for the beams. As observed, the median curve did not change due to the assumed probability density function, but the mean values are significantly lower. In fact, the CMS mean computed based on the lognormal distribution assumption is close to the CMS median values. The CMS lognormal mean is reduced because it was computed based on the median, $\bar{\mu}$, and standard deviation of the log of the data, σ_{lnx}, which were calculated using the 84th and 16th percentiles. As a result, extreme values that may arise due to building collapse for some realizations are not considered in the median computation. The PEER lognormal mean was also reduced because of the use of Eqns. (6) and (7). PEER median and mean values are larger than those obtained from the CMS method, but this is partly due to the fact that $S_a(T_1)$ is larger for the PEER method (Fig. 3b). Fig. 6(a) and Fig. 6(b) present similar results for 4- and 8-story building columns computed under the assumption of a lognormal distribution.

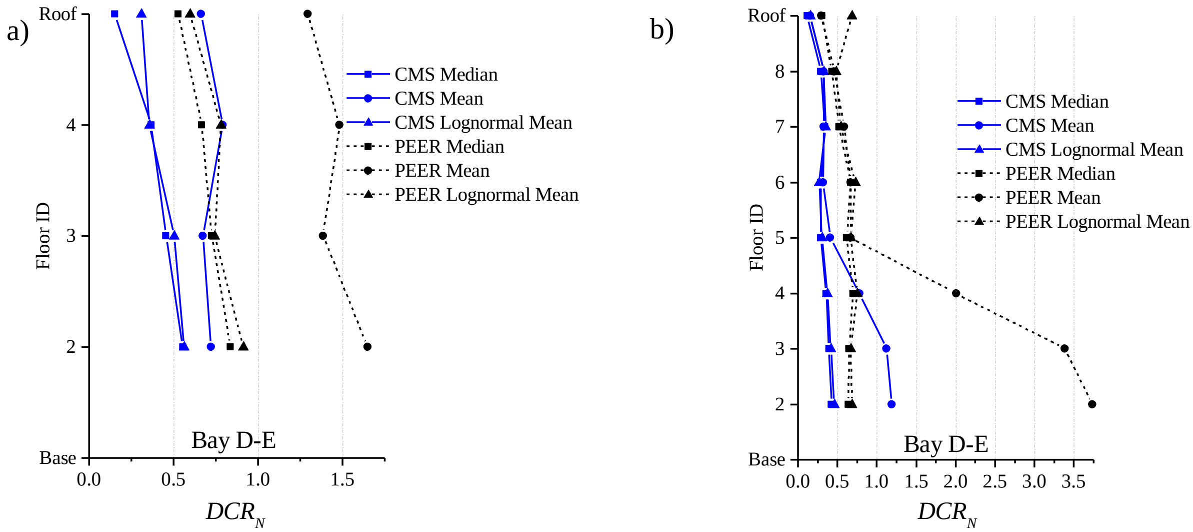


Fig. 5 – Comparison of max DCR_N values of the reduced beam sections computed for ground motions selected using the CMS and PEER ground motion selection methods for the (a) 4-story and (b) 8-story building.

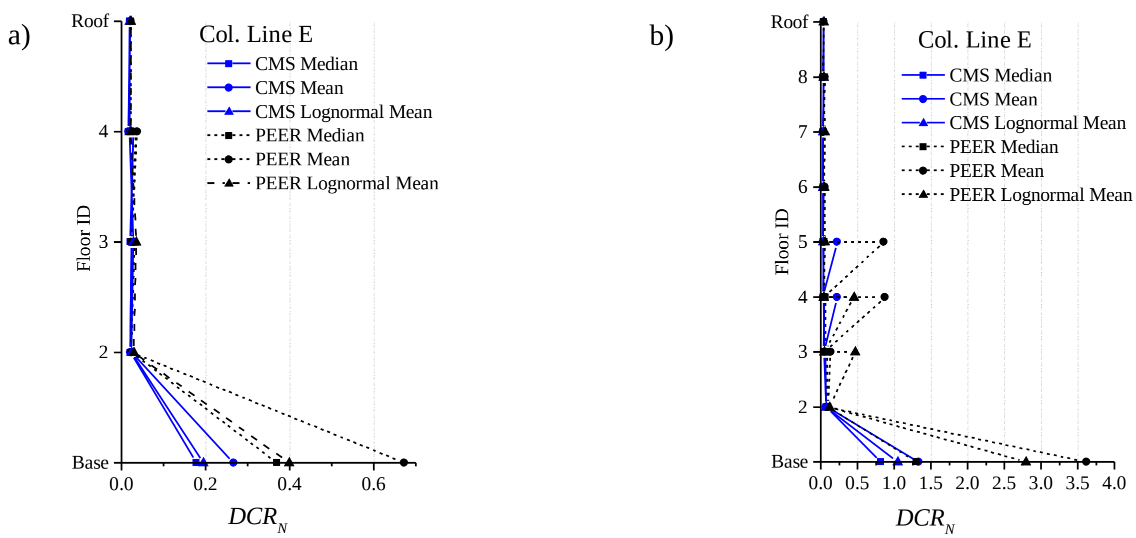


Fig. 6 – Comparison of max DCR_N values of the column hinges for (a) the 4-story and (b) the 8-story building computed for ground motions selected using the CMS and PEER methods.

6.2.4 Uncertainty in Response Prediction Using CMS and PEER

One of the primary goals of efficient ground motion selection methods is to predict structural seismic response with the smallest possible number of records. Comparison among ground motion selection approaches can be done through various metrics. Each ground motion selection method aims to select ground motions that produce a response spectrum that closely matches the prescribed target spectrum. Regardless of the importance of the target spectrum, the selection procedure that leads to a smaller variability on the structural response is considered more suitable. To determine the uncertainty associated with the results produced by each ground motion selection approach, the dispersion of the DCR_N values is computed for each element. To establish a fair comparison between the statistical results obtained from the two methods, the PEER spectrum is scaled down to match the MCE_R spectral acceleration at T_1, because the use of a larger $S_a(T_1)$ in the PEER spectrum may lead to larger nonlinear response and even more collapses, leading to a larger dispersion. Fig. 7 (a) and (b) compare the means and medians of the beam DCR_N obtained from the CMS and the scaled down PEER ground motion for the 4- and 8-story buildings, respectively. The computed dispersion for the PEER ground motions scaled to $S_a(T_1)$ value of the conditional mean spectrum is compared to the CMS results at the controlling conditioning period. The dispersion of the RBS connections located at the bay D-E of the 4- and 8- story buildings are summarized in Fig. 8 and Fig. 9, respectively. The second column in the tables shown in Fig. 8 and Fig. 9 presents the standard deviation obtained from the CMS method, which corresponds to the conditioning period with the largest mean demand (shown in parenthesis). The third column shows the dispersion derived from the PEER method, and the fourth column is the ratio of the standard deviation between the CMS and PEER method.

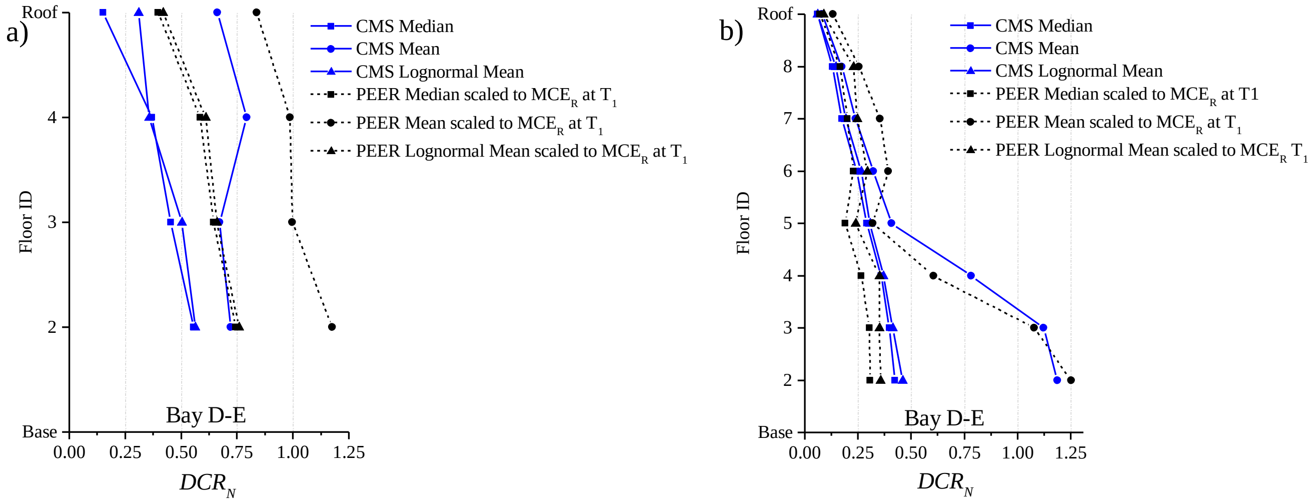
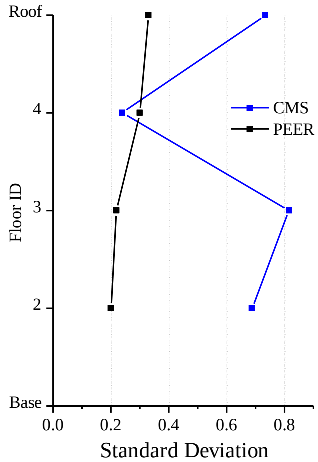


Fig. 7 – Comparison of max DCR_N values of the reduced beam sections computed for ground motions selected using the CMS and PEER ground motion selection methods scaled down to $Sa(T_1)$ for the (a) 4-story and (b) 8-story building.

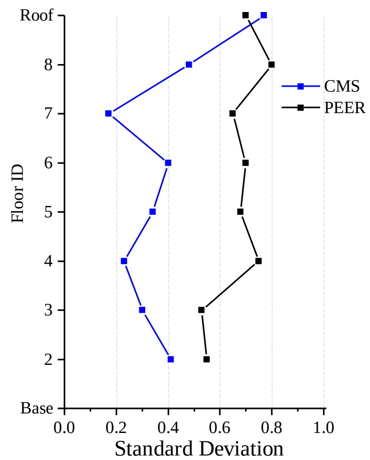
The results show that the CMS ground motions produce a higher dispersion in the predicted structural response quantified as DCR_N for the 4-story frame with the exception of the fourth story. However, in the 8-story building the dispersion trend is different, and the CMS method produces lower dispersion than that of the PEER method, with the exception of demands at the roof level. The main difference is that the larger CMS dispersion in the 4-story frame corresponds to the controlling period $0.4T_1$, whereas most floors in the 8-story building have T_1 as the controlling period. When the mean demand parameter is controlled by the conditioning period T_1, the CMS method generally leads to smaller dispersion. The reason is that the dispersion is null for the elastic period T_1, and the variability of higher modes (*i.e.*, shorter periods) and inelastic longer periods is less relevant on the overall response because the average accelerations at these other periods are smaller than those of the target spectrum, MCE_R (see Figs. 1 and 3a). However, when the mean demand is controlled by a different conditioning period, other than T_1, the dispersion of $S_a(T_1)$ is not zero, and the dispersion increases even within the elastic system performance. Moreover, the dispersion at higher modes is also different from zero, unless the controlling period coincidentally corresponds to one of these higher modes.



Story Number	$\sigma_{CMS}{}^*$	$\sigma_{PEER\ @\ T_1}$	$\frac{\sigma_{CMS}{}^*}{\sigma_{PEER\ @\ T_1}}$
2	0.69 ($0.4T_1$)	0.20	3.48
3	0.82 ($0.4T_1$)	0.21	3.85
4	0.24 ($0.4T_1$)	0.29	0.82
Roof	0.73 ($0.4T_1$)	0.33	2.24

* σ_{CMS} is computed for the controlling conditioning period.

Fig. 8 – Standard deviation of the DCR_N results for the RBS connections at Bay D-E of the 4-story building using CMS at the controlling period and PEER methods.



Story Number	$\sigma_{CMS}{}^*$	$\sigma_{PEER\ @\ T_1}$	$\frac{\sigma_{CMS}{}^*}{\sigma_{PEER\ @\ T_1}}$
2	0.41 (T_1)	0.55	0.74
3	0.30 (T_1)	0.53	0.56
4	0.23 (T_1)	0.75	0.31
5	0.34 (T_1)	0.68	0.50
6	0.40 (T_1)	0.70	0.57
7	0.17 ($0.4T_1$)	0.65	0.26
8	0.48 ($0.2T_1$)	0.80	0.60
Roof	0.77 ($0.2T_1$)	0.70	1.09

* σ_{CMS} is computed for the controlling conditioning period.

Fig. 9 - Standard deviation of the DCR_N results for the RBS connections at Bay D-E of the 8-story building using CMS at the controlling period and PEER methods.

7. Conclusions

Sets of 14 ground motions were selected using the CMS and PEER methods, and used as the input for nonlinear dynamic analysis of 4- and 8-story steel special moment frames. The mean and median normalized demand to capacity ratios were calculated for various components and used to determine the differences in structural response predicted using the two ground motion selection methods. The results show that the CMS method renders reduced mean and median demand-to-capacity ratios for the reduced beam section, and column hinge components, compared to the PEER method. The dispersion of the predicted structural response was calculated to determine the confidence provided by each method. The CMS method can provide lower dispersion, higher confidence, in the predicted response for buildings in which the controlling period is T_1. The results showed that the underlying distribution of the analysis results can lead to a different mean predicted response and as a result different retrofitting decision. The findings of this study showed that the ground motion selection methodology has a significant effect on the assessment outcome. Though the CMS method requires more effort in the selection and assessment process, it provides a ground motion set that, on average, leads to reduced building demands that are more realistic. This study advocates consideration of the CMS method as an alternative ground motion selection approach in evaluation standards, such as ASCE 41.

8. Disclaimer

Certain commercial software may have been used in the preparation of information contributing to this paper. Identification in this paper is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that such software is necessarily the best available for the purpose.

9. References

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