UCI-UniNa joint research on engineering validation of ground motion simulations for past events

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SUMMARY:
The Southern California Earthquake Center (SCEC) has established a Technical Activity Group (TAG) focused on Ground Motion Simulation Validation (GMSV) in order to develop and implement testing/rating methodologies via collaboration between ground motion modelers and engineering users. Within the GSMV TAG, a collaborative research started in February 2011 between the University of California, Irvine (UCI) and the University of Naples Federico II, Italy (UniNa) to validate simulated ground motions for past earthquakes using engineering demand metrics, i.e., elastic and inelastic response spectra and generalized interstory drift and floor accelerations spectra.
In the present paper, we summarize the results of the first phase of this ongoing study. In particular, the aim is to address, on a statistical basis, whether simulated GMs for four historical earthquakes are biased in terms of their median linear and nonlinear response characteristics in comparison with real records. We also look into dispersion (i.e., intra-event variability) of response to recorded and simulated GMs. Hypothesis tests on selected samples are also carried out to assess the statistical significance of the result found in terms of peak and, in the case of nonlinear systems, cyclic response.

Keywords: Ground motion, hybrid broadband simulation, SDoF, MDoF, statistical analysis

1. INTRODUCTION AND MOTIVATION

For the purposes of building seismic performance assessment and design for target performance, the input earthquake ground motions signals (simply GMs hereinafter) can either be: (1) real (i.e., recorded) GMs from past earthquakes, (2) artificially (i.e., stochastic-based) simulated or spectrally matched GMs created by manipulating the frequency content and intensity of recorded GMs to match a specific hazard spectrum, or (3) physics-based simulated GMs. Real records have been traditionally considered the best representation of seismic loading for structural assessment and design, motivating attempts to develop tools for computer aided code-based record selection, e.g. Iervolino et al., 2012 and Smerzini et al., 2012. Given the advances in the understanding of fault rupture process, wave propagation phenomena and site response characterization, simulated GMs of type (3) appear to be one of the viable and attractive alternatives to the very limited amount of recorded GMs, particularly (but non only) in the nearby-field from large earthquakes. The current state-of-the-art simulation procedures are based on a hybrid approach that combines deterministic low frequency synthetics up to a maximum frequency of typically 1-2 Hz with high frequency stochastic simulation above this upper cutoff frequency (see for example Graves and Pitarka, 2010). However, to date, simulated GMs have not found significant practical application because of a general sense among engineers that they have not been adequately validated against recorded data. Moreover, they are not yet readily available to engineers. This latter issue traditionally favored the use of spectrum matching accelerograms, either artificial or obtained through manipulation of real records, even if they have not yet extensively validated.
A Technical Activity Group (TAG) focusing on Ground Motion Simulation Validation (GMSV) has been established by Southern California Earthquake Center (SCEC) to develop and implement

testing/rating methodologies via collaboration between ground motion modelers and engineering users. A 2011 Workshop on this topic has identified some initial efforts as potential priority activities in this area, including i) validation of simulated ground motions for past earthquakes using elastic and inelastic response spectra; 2) validation of simulated ground motions for past earthquakes for multi-degree-of-freedom (MDoF) linear and nonlinear building systems. To this aim, a collaborative research started in February 2011 between the University of California, Irvine (UCI) and the University of Naples Federico II, Italy (UniNa).

In the present paper, we summarize the results of the first phase of the UCI-UniNa ongoing research within the GSMV TAG. Elastic and inelastic single degree of freedom (SDoF) and generalized elastic MDoF are considered. In particular, the aim is to address, on a statistical basis, whether simulated GMs for four historical earthquakes are biased in terms of their median linear and nonlinear response characteristics in comparison with real records, We also look into dispersion (i.e., intra-event variability) of response to recorded and simulated GMs. Hypothesis tests on selected samples are also carried out to assess the statistical significance of the result found in terms of peak (displacement and acceleration) and, in the case of nonlinear systems, cyclic response. Further efforts will aim at validation of simulated ground motions for past earthquakes using high-rise and low-rise MDoF nonlinear building systems and reinforced concrete bridges with skew-angled seat-type abutments. The results of this study are directly relevant to the engineering community establishing validated reference sets of synthetically generated broadband GM, although they may also provide feedback for seismologists who generate simulated GMs for engineering applications.

2. DESCRIPTION OF SYNTHETIC AND REAL GROUND MOTION DATASETS

Graves and Pitarka (2010) developed and validated (in terms of elastic spectral ordinates) a hybrid broadband (0-10 Hz) GM simulation methodology that uses simple kinematic representation of slip velocity and rupture velocity on the fault surface, see also Graves and Aagaard (2011). More specifically, to simulate broadband time histories, the GMs are computed separately in the short-period and long-period ranges and then combined into a single broadband time history, because GMs have fundamentally different characteristics in these two period ranges. At long periods (longer than 1s, i.e., $f \leq 1$ Hz,), strong GMs are deterministic in the sense that rigorous seismological models are capable of matching not only the spectral amplitudes but also the waveforms of recorded long-periods GMs, once the rupture model of the earthquake and the seismic velocity structure of the region surrounding the earthquake are known. At short periods (shorter than 1s, i.e., $f > 1$ Hz), strong GMs become increasingly stochastic in nature. Seismological models are generally capable of matching the spectral ordinates of the short-period GMs but are generally not capable of matching the recorded waveforms. The transition from deterministic to stochastic behavior appears to be due to a transition from coherent source radiation and wave propagation conditions at long periods to incoherent source radiation and wave propagation conditions at short periods. For both short and long periods, the effect of relatively shallow site condition, as represented by shear wave velocity in the upper 30 m (V_{s30}) are accounted.

Four historical earthquakes were modeled by Graves and Pitarka (2010) and are used in the present study: 1979 M_w 6.5 Imperial Valley, 1989 M_w 6.8 Loma Prieta, 1992 M_w 7.2 Landers, and 1994 M_w 6.7 Northridge. All other required source parameters (e.g., rupture propagation time, rise time, slip function, fine-scale slip heterogeneity) are developed using the scaling relations presented by Graves and Pitarka (2010). Furthermore, the methodology provides a reliable framework to generate rupture descriptions for future earthquakes, as demonstrated by Graves and Aagaard (2011). Complete details of the rupture generation procedure are given in Graves and Pitarka (2010).

For each earthquake, the developed model covers a wide area surrounding the fault and including several strong motion recording sites according to the NGA database: 33 for the Imperial Valley earthquake, 71 for the Loma Prieta earthquake, 23 for the Landers earthquake and 133 for the Northridge earthquake. Only a limited number of these sites are used here, i.e., those with a usable bandwidth of the real records exceeding 0.1s-8s, yielding a total of 126 sites, see Figure 2.1. Such large bandwidth for recorded motions provides justifiable means to cover a good range of actual nonlinear systems where period elongation can force the effective period of the system be much larger than its initial period. In fact, in some cases, especially for degrading and evolutionary systems, as the damage severity progresses, the period elongation can force the initial period outside the suggested usable bounds and the usable lower frequency will tend to be somewhat higher (more restrictive). Moreover, the correlation between inelastic spectral ordinates at the fundamental period and at higher periods may be important. Hence, the results presented in this paper for very long period-structures (e.g., 6-8s), in the severely nonlinear range, should be considered with caution.

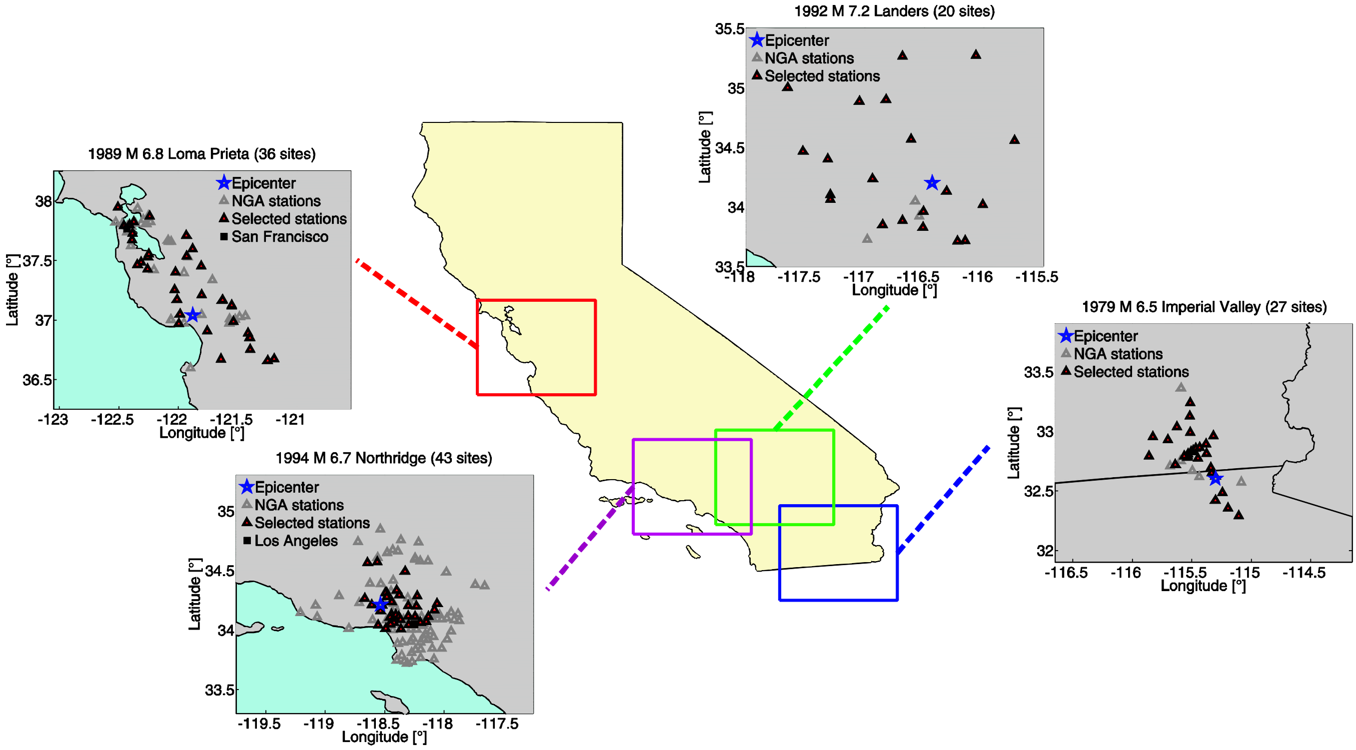

Figure 2.1. Maps of the considered earthquakes. The star is the epicenter and the grey triangles are recording stations of the NGA database for which the simulations are available. The red triangles are recording stations considered in this study.

3. VALIDATION OF SIMULATED GROUND MOTIONS USING ELASTIC AND INELASTIC RESPONSE SPECTRA

As first step, the pool of GMs described in previous section, recorded and simulated, were used to perform NLDA on a total of 180 SDoF systems, representing combinations of variation in three parameters:

- SDoF fundamental period (T): 18 periods between 0.1s and 5s are considered in this study. The period range is sampled with a 0.1s step from 0.1s to 0.5s, with a step of 0.25s between 0.5s and 1s, with a step of 0.5s between 1s and 5s, and with a step of 1s between 5s and 8s.
- Strength reduction factors (R): this parameter is the ratio of the GM record elastic demand and the yield strength of the SDoF system, F_y. R is varied in order to describe elastic/inelastic structural behavior; from elastic (R = 1), for completeness and checking purposes, to mildly inelastic (R = 2) and severely inelastic structures (R = 8). Note that the peak deformation experienced by an elastic structure is a GM and SDoF period specific quantity. We obtain F_y for a given R value for each record in the dataset (*constant-R approach*) to account for the large variability of the GM features (e.g., in terms of spectral ordinates).
- Hysteretic behavior: two hysteretic behaviors are considered in this study: non-degrading and non-evolutionary, and degrading and evolutionary. A non-degrading elastic-plastic with positive 3% strain-hardening (EPH) model represents the non-degrading and non-evolutionary SDoF system. The degrading and evolutionary SDoF system (ESD) comprises a -10% strain-hardening (10%

softening) and a residual strength of 0.1· F_y. The simple peak-oriented model is considered to account for the cyclic stiffness degradation while strength cyclic deterioration is not considered (Ibarra et al., 2005). All ESD systems have ductility before reaching the residual strength, evaluated as the ratio between ultimate displacement (Δ_u) and yielding displacement (Δ_y) in the backbone curve, i.e., a *ductility limit*, equal to 10. A mass-proportional viscous damping coefficient corresponding to a 5% critical damping ratio is used and kept constant throughout the time history analyses.

Two representations of SDoF response, engineering demand parameters (EDP), are considered in this investigation: *inelastic displacement* ($\Delta_{inelastic}$), and *equivalent number of cycles* (N_e). In particular, N_e is given by the cumulative hysteretic energy (E_H), evaluated as the sum of the areas of the hysteretic cycles (not considering the contribution of viscous damping) normalized with respect to the largest cycle, evaluated as the area underneath the monotonic backbone curve from the yielding displacement to the peak inelastic displacement, ($A_{plastic}$), see Eqn. (3.1).

$$N_e = \frac{E_H}{A_{plastic}} \tag{3.1}$$

Values of N_e close to 1 show the presence of a large plastic cycle in the non-linear response, while high values of N_e are indicative of the presence of many plastic cycles; N_e generally decreases with the period in the short period range and increases with R (Manfredi, 2001). In addition, N_e varies largely depending on the GMs features, from values close to 1 for impulsive earthquakes to value of about 40 for long-duration earthquakes.

These two parameters are considered to investigate both the peak displacement demand, and the cyclic seismic response and, in particular, N_e is a parameter that well-captures the effects of GM potential with respect to structural response in terms of dissipated hysteretic energy.

3.1 Results and discussions

All GMs (recorded and simulated) selected for each earthquake are used as input for NLDA applied to all the SDoF systems considered, yielding a total of 45,000 NLDAs performed. Only horizontal component of GMs (i.e., north-south, NS, and east-west, EW) are used, while vertical component is neglected. The spectral responses for the two horizontal components at each station is computed and then combined into an "average" spectral response by using the geometric mean. For each earthquake and each EDP ($\Delta_{inelastic}$ and N_e), the median value (i.e., the exponential of the mean of the natural log of the EDP across all the available stations) for the synthetic records divided by the median value for the real dataset is computed across the considered period range (for different R values). A ratio above unity, if statistically significant, means overestimation of response by simulations, and the opposite if smaller than one.

In order to provide a measure of inherent intra-event variability in the simulations compared to that of real GMs, also the ratio of the standard deviation (of the natural log of the data) for simulated and recorded GMs (for all sites and distances in a given earthquake) is computed as a function of the period and R. A line above unity means relatively more record-to-record variability produced by simulated GMs whereas the opposite is true for a line below one.

A direct comparison of response statistics is acceptable as the simulated datasets are developed to match exactly the same earthquakes and site conditions (i.e. at the same stations) of the real recordings.

As an example, Figure 3.1a shows the ratio of the median spectrum in terms of $\Delta_{inelastic}$ from the simulated GMs to the median spectrum (again in terms of $\Delta_{inelastic}$) from the recorded GMs for Northridge; Figure 3.1b shows the same ratio in terms of N_e. Figure 3.1c shows the ratio of the standard deviations of the data in terms of $\Delta_{inelastic}$ from the simulated GMs to the standard deviation of the data (again in terms of $\Delta_{inelastic}$) from the recorded GMs; Figure 3.1d shows the same ratio in terms of N_e. Figure 3.1. refers to EPH (non-degrading, non-evolutionary) systems; results for the other events and model are not shown to save space but similar observations can be drawn for these cases.

In particular, looking at post-elastic response, bias (i.e., the departure of the considered ratio from unity) in estimation of seismic response of SDoF systems depends on the considered period and strength level. Results are very similar for both EPH and ESD systems, although, in the case of ESD systems (not shown here) the differences are slightly larger and more *R* dependent. Systematic deviations seem to be concentrated in the zone of semi-stochastic simulation (at very short periods), around 1s, for some cases, and at the very long periods (especially at high nonlinearity levels). The fact that bias in terms of peak response is close to zero in the moderate-long periods part of the inelastic spectra is essentially the result of the *equal displacement rule* (Veletsos and Newmark, 1960), quite well observed for both recorded and simulated GMs. The observed differences at given periods are likely due to systematic differences in the average shape around those periods of the linear response spectra generated by synthetic and by real GMs. When the response of an SDoF systems becomes severely nonlinear, its effective vibration period lengthens significantly, especially at short periods, and, therefore, it becomes dependent on the frequency content of the record in a fairy large bandwidth and not only in the neighborhood of the initial elastic natural period of vibration.

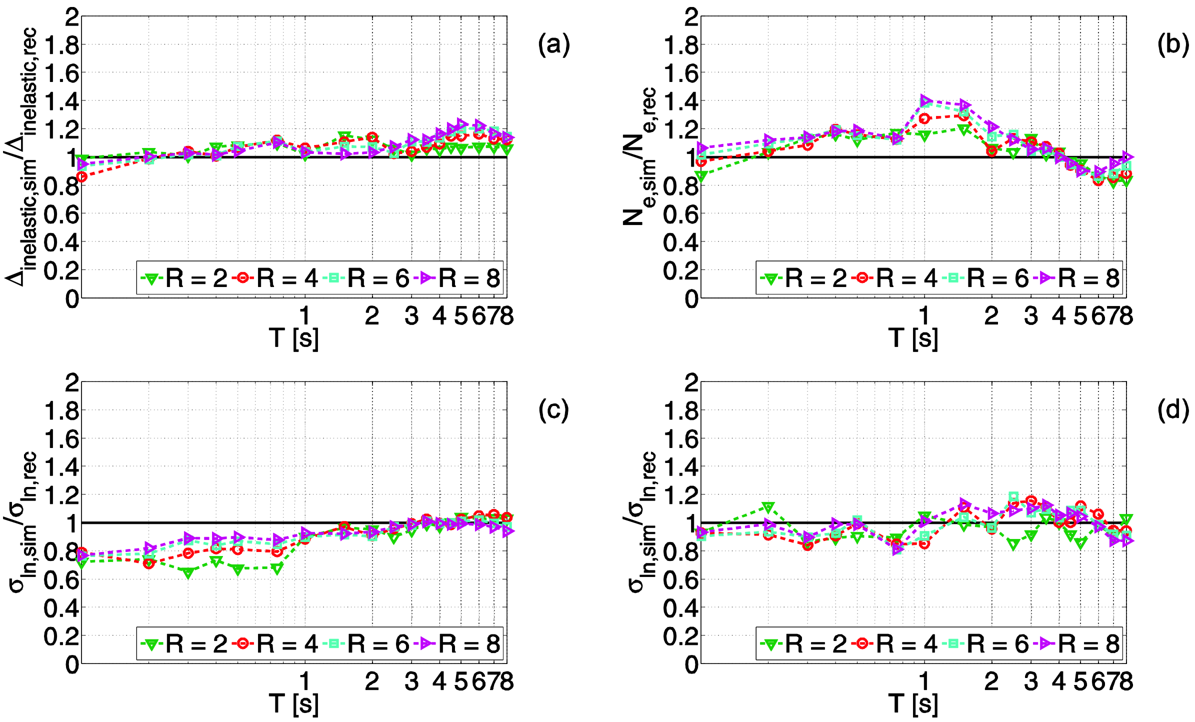

Figure 3.1. Ratios of the medians [(a), (b)] and standard deviations [(c), (d)] of the inelastic spectra (in terms of $\Delta_{inelastic}$ and N_e) for simulated GMs to the corresponding quantity computed for the recorded GMs for the Northridge earthquake (EPH model).

Moreover, simulated records tend to produce nonlinear demands that are often less variable (i.e., lower intra-event variability is observed) compared to those caused by real records, especially at short periods. This trend of relatively low intra-event variability in the simulations has been noted previously by Star et al (2011). Seyhan et al (2012) have recently proposed a revision to the simulation approach that incorporates greater stochastic variability in the high frequency portion to address this issue, although this revision has not yet been applied to the simulations considered in the current analysis.

Results of hypothesis tests, not shown here for brevity, confirm the considerations based on the visual inspection of Figure 3.1. Complete details of the statistical analysis, including all the considered events, are given in Galasso et al. (2012a). In the same paper, a sensitivity analysis shows that both the level and trend of the observed values of (i) inelastic displacement as a function of source-to-site distance and soil class and (ii) equivalent number of cycles as a function of integral intensity measures, are matched well by the simulation. Some differences exist in the number of pulse-like GMs in the simulated dataset (with respect to the recorded one for the same earthquake) and in the values of pulse periods for these records, confirming that strong directivity effects in the simulations require more study.

4. VALIDATION OF SIMULATED GROUND MOTIONS FOR MULTI-DEGREE-OF-FREEDOM (MDoF) LINEAR BUILDING SYSTEMS

For some structures, tall buildings for example, the higher modes contributions may become substantial and deformation of the building would thus be dominated by a wave-like response. Then, the traditional SDoF spectral analyses may significantly underestimate local structural deformation particularly for large period structures. Furthermore, if displacement response spectrum ordinates are used, they only provide a measure of the overall lateral deformation (and acceleration) in the structure and do not take into account the concentration in lateral deformations in certain stories that usually occur in actual buildings. Finally, the contribution of higher modes is also particularly important for predicting acceleration demands in buildings (e.g., Miranda and Taghavi, 2005).
As deformations in buildings can be isolated into two types, (1) shear-type, and (2) flexural-type, MDoF systems considered in this study are modeled as equivalent continuum structures that consist of a flexural cantilever beam coupled with a shear cantilever beam (both with uniform mass distribution), e.g., Miranda (1999); Miranda and Akkar (2006). Such model (Figure 4.1) is a viable tool to approximate real buildings, especially those tall, ranging from moment-resisting frames to shear wall systems, and for which the higher-mode contributions may become important. Moreover, it permits obtaining estimates of seismic response of multistory buildings with only three parameters: T_1, ξ, and α, that are, the fundamental period, the critical damping ratio at the first mode of vibration, and a non-dimensional quantity controlling the degree of contribution of flexural and shear deformations in the MDoF's total deformation, respectively. By varying α one can control relative contributions of the two types of deformation on the total response, providing the opportunity to account for a wide range of modes of deformation that represent more closely those of multistory buildings[1]. In fact, the lateral deflected shapes of buildings, whose lateral resisting system consists only of structural walls, can usually be approximated by α between 0 and 2. For buildings with dual lateral resisting systems consisting of a combination of moment-resisting frames and shear walls or a combination of moment-resisting frames and braced frames, values of α are typically between 1.5 and 6. For buildings whose lateral resisting system consists only of moment-resisting frames, values of α are typically between 5 and 20.

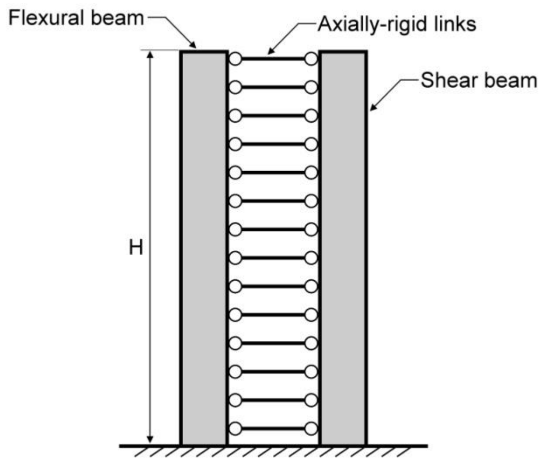

Figure 4.1. Simplified model used in generalized interstory drift spectrum.

[1] However, this approach for approximating buildings inherits some of the limitations and assumptions of modal analysis, such as assuming a linear elastic behavior and a classical damping. Hence, the method is aimed at the estimation of seismic demands at performance levels in which the building is expected to respond elastically or with very limited levels of nonlinearity, such conventional buildings subjected to moderate earthquake GMs or critical facilities during sever earthquake GMs.

More specifically, in order to study the dynamic response of a wide range of buildings, a number of simplified continuum systems are selected considering: (1) 18 (fundamental) oscillation periods, simply T hereafter, between 0.1s and 8s; (2) three shear to flexural deformation ratios, α, to represent respectively shear walls structures (α = 0.1), dual systems (α = 8), and moment-resisting frames (α = 30); (3) two stiffness distribution along the height of the systems; i.e., uniform and linear. In the latter case, the ratio of the lateral stiffness at the top of the structure to the lateral stiffness at the base is assumed equal to 0.25.
Demand spectra in term of maximum interstory drift ratio (MIDR), i.e., the maximum time-peak rotation over the height of the building, and critical story (CS), i.e., the height of maximum interstory drift normalized with respect to the total height of the system were derived. In addition, for two actual tall buildings in California, the interstory drift ratio distribution over the height and the floor acceleration spectra are obtained and compared for both recorded and simulated time histories.

4.1 Results and discussions

As for the SDoF systems, all GMs (recorded and simulated) selected for each earthquake are used as input for the seismic analysis of MDoFs discussed in the previous section; a total of about 27,000 analyses are performed (also in this case, the spectral responses for the two horizontal components at each station is computed and then combined into an "average" spectral response by using the geometric mean). For each earthquake and each engineering demand parameter, EDP, i.e., MIDR and CS, the median value (i.e., the exponential of the mean of the natural log of the EDP across all the available stations) for simulated records divided by the corresponding median value for the recorded dataset is computed and plotted across the considered period range (for the different α values).

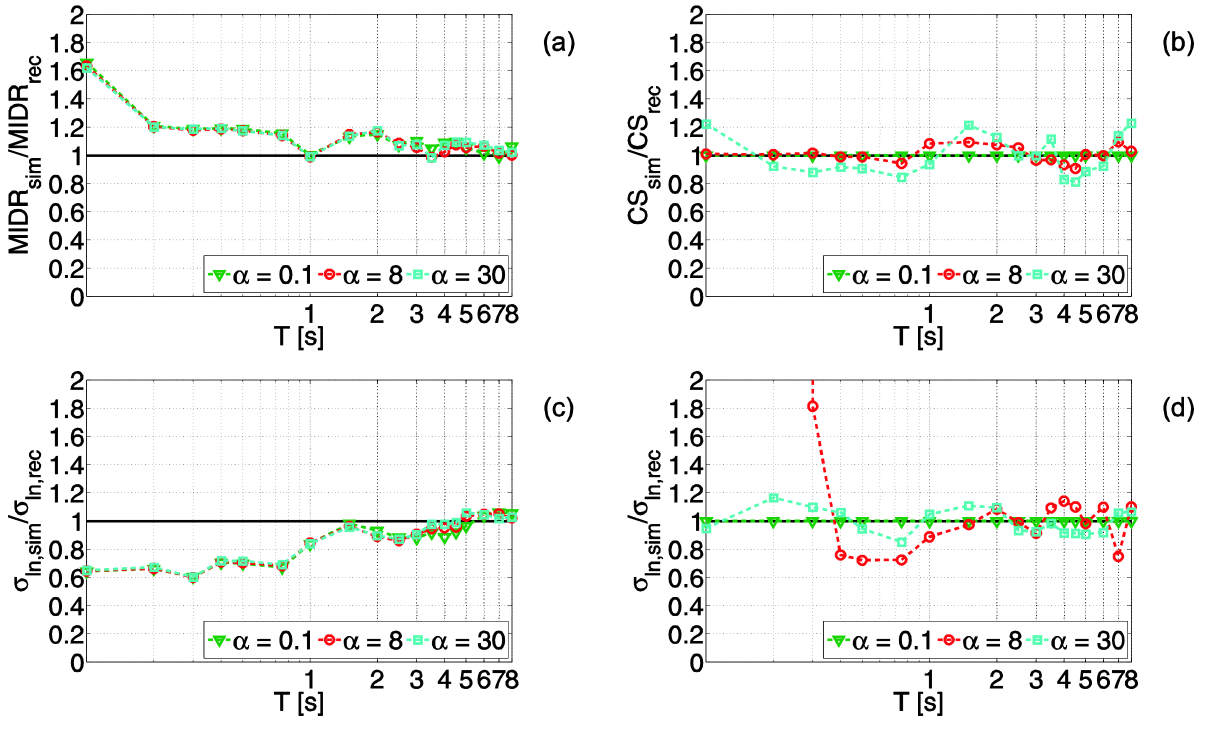

Figure 4.2. Ratios of the medians [(a), (b)] and standard deviations [(c), (d)] of the generalized spectra (in terms of MIDR and CS) for simulated GMs to the corresponding quantity computed for the recorded GMs for the Northridge earthquake.

Also in this case, in order to provide a measure of inherent variability in the simulations compared to that of real GMs, the ratio of the standard deviation (of the natural log of the data) for recorded and simulated GMs was plotted as a function of the period and α.
As an example, the median value of MIDR for the simulated records ($MIDR_{sim}$) divided by the median

value of MIDR for the recorded dataset ($MIDR_{rec}$) is plotted across the period range of 0.1s to 5s in Figure 4.2a for the three considered α values (Northridge event). Figure 4.2c shows the ratio of the standard deviation of MIDR (log of the data) for synthetic GMs divided by the standard deviation of MIDR (log of the data) for recorded GMs. The same ratios but in terms of CS are reported in Figures 4.2b and 4.2d. Figure 4.2. refers to the case of uniform stiffness along the height; the same conclusions hold in the case of buildings with linear variation of stiffness along the height.

Looking at elastic response based on the simplified model, bias is *period*- and, in the case of MIDR response, slightly α-dependent. Systematic deviations seem to be concentrated in the zone of semistochastic simulation (at very short periods) and around 1s.

Except for the Imperial Valley event (not shown here for brevity), the standard deviations of the spectra of the real records are generally larger compared to the simulated GMs, particularly at the shorter periods, as for the SDoF case. In the case of the Imperial Valley event, the standard deviation of response of simulated records are larger than those of recorded ones across the entire period range (the considered ratio is almost constant and above the unity). This can be likely attributed to the presence in the simulated dataset of GMs featuring strong coherent velocity pulses and then large elastic response.

Results of hypothesis tests, not shown here for brevity, confirm the considerations based on the visual inspection of Figure 4.2. Complete details of the statistical analysis, including all the considered events, are given in Galasso et al. (2012b).

4.2 Case study structures

For two selected case-study structures in California, the floor accelerations spectra (for four different locations along the height) are obtained and plotted in terms of ratio between median of structural response to simulated and recorded GMs. Floor accelerations spectra allow the estimation of accelerations demands at different frequencies. This information is useful, for example, for acceleration-sensitive non-structural components (characterized by a weight smaller than the weight of the building) for which the peak floor acceleration is not enough. Given the different properties of the two buildings in each horizontal direction, separate comparisons for each component of GM (i.e., north-south, NS, and east-west, EW) are performed.

The first structure (SF48) is a pyramidal-shape 257m tall building in San Francisco, built in 1972; its lateral resisting system consists of interior and exterior steel moment-resisting frames. It was shaken by the 1989 Loma Prieta earthquake. The second structure considered (LA52), built in 1990, is in Los Angeles and has 52 stories above ground; it has a square floor plan and the lateral resisting system, in both directions, consists of concentrically braced steel frames at the core with outrigger moment-resisting frames in the exterior. This structure was hit by several earthquakes, including the 1994 Northridge event.

Both structures are instrumented, allowing the estimation of the parameters that are needed in each direction to perform the simplified analysis, see Reinoso and Miranda (2005) for details. The parameters used for each of the buildings are listed in the last three columns of Table 4.1. (the damping ratio of all modes is assumed to be the same in order to reduce the number of parameters required to fully define the simplified model to three).

The median value of floor accelerations for the simulated records (acc_{sim}) divided by the median value of floor accelerations for the recorded dataset (acc_{rec}) is plotted across the period range of 0.1s to 5s in Figure 4.3a for the SF48 building subjected to the Loma Prieta event, and in Figure 4.3b for the LA52 building shacked by the Northridge earthquake. In both panels, four different locations along the height of the building, expressed in terms of nondimensional height *z*, are considered, i.e., 25%, 50%, 75% and the roof. The considered ratios seem to be slightly dependent on the *z* values in all the period range and on the GM component. The results in Figure 4.3 confirm the results found in terms of MIDR for the Loma Prieta and Northridge earthquakes (Figure 4.2 for Northridge): simulated GMs tend to overestimate the accelerations demands in the short periods part of the spectra and these differences are statistically significant until 0.5s in the case of SF48 building and until 1s in the case of LA52 building. In the moderate to long period range, simulation matches well the acceleration demands produced by recorded GMs and the bias is close to zero for a wide period range.

Table 4.1. Buildings and events used in this study (adapted from Reinoso and Miranda, 2005)

ID	Location	Stories	Earthquake	Ep. Dist.	Comp.	T	α	ξ
SF48	San Francisco	48	Loma Prieta	97km	NS	3.57	25.0	1.2
					EW	3.70	25.0	1.5
LA52	Los Angeles	52	Northridge	31km	NS	5.90	9.8	1.0
					EW	6.20	6.0	1.5

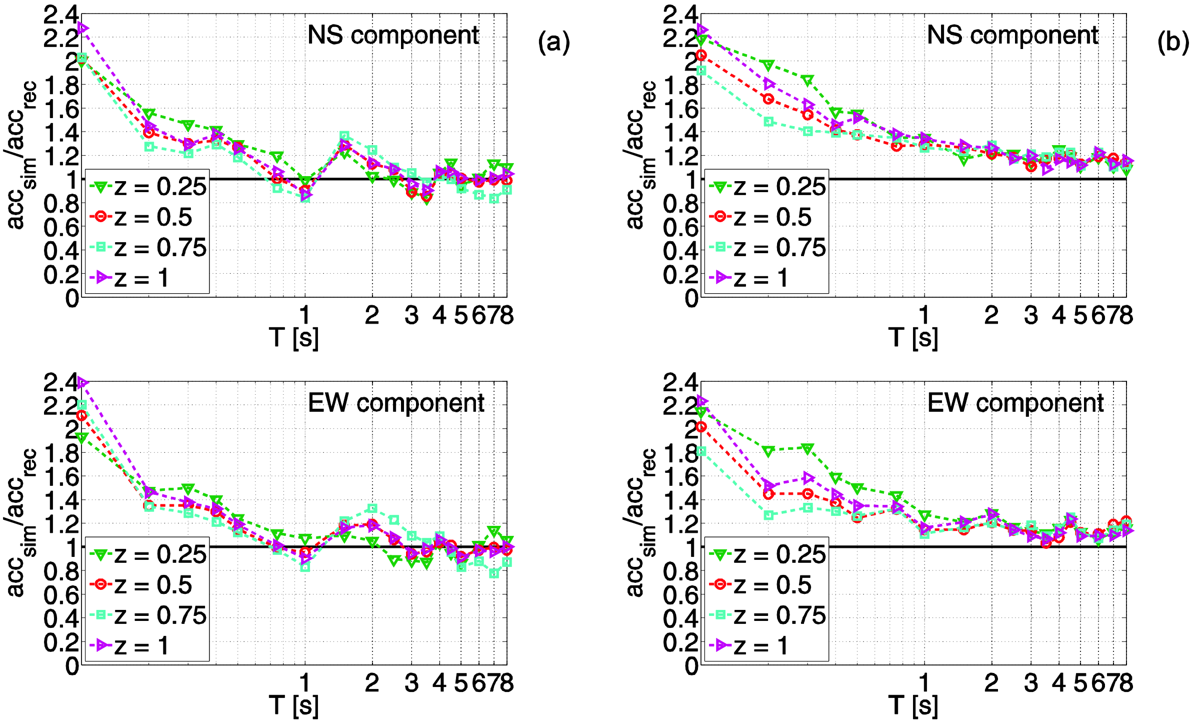

Figure 4.3. Ratios of the medians of the floor accelerations spectra for simulated GMs to the corresponding quantity computed for the recorded GMs for the (a) SF48 buildings and (b) LA52 building.

5. CONCLUSIONS

Design of new structures or assessment of the existing ones may be complicated by the inherent rareness or total absence of suitable real (i.e., recorded) accelerograms for the earthquake scenarios that dominate the seismic hazard at a given site. Thereby, synthetic records may be an attractive alternative as input to nonlinear dynamic analysis, if it is proven their structural response equivalency with respect to real ground motions with same seismological features.

This paper summarized the results of a larger study on the statistical comparison between simulated and recorded GMs in terms of elastic and post-elastic seismic response. This was pursued by considered elastic and inelastic SDoF systems and generalized linear MDoF building systems.

We show that simulation matches well the seismic demands produced by recorded GMs, although, some differences between median estimate of seismic demand obtained by using real records and that obtained by simulations are observed, especially in the short periods part of the spectra, where the simulation is semistochastic. The observed differences are due to systematic differences in the average shape around those periods of the linear response spectra generated by synthetic and by real GMs.

Moreover, the record-to-record variability of seismic demands produced by simulated and recorded GMs may be different, especially in the short period range. Hypothesis tests are carried out with the aim of assessing quantitatively how significant the estimated biases can be. Tests have shown a statistical significance of the bias of simulated record in terms of both elastic and inelastic response only for short periods structures.

Finally, using two case-study structures, the comparison between the median floor acceleration spectra confirms the result found in terms of generalized MIDR spectra.

While results of this study are most directly relevant to the engineering community in order to establish validated reference sets (but also an effective methodology of engineering validation) of synthetically generated broadband GMs, they may also provide insight for seismologists who generate simulated records for engineering application into the practical effect of their simulation techniques.

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