Atti del 37° Convegno Nazionale

tenutosi a Bologna, 19-21 novembre 2018

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2018 - 2.2

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SYNTHETIC ACCELEROGRAMS FOR HAZARD EVALUATION AND RESPONSE-HISTORY ANALYSIS OF BUILDINGS

M. Fasan, M. Barnaba
Department of Engineering and Architecture, University of Trieste, Italy

Introduction. Non-linear Time History Analysis (NLTHA) of structures is the most sophisticated tool used to understand the real dynamic behaviour of structures (FIB, 2012). The goodness of results relies on an accurate definition of the materials properties, their hysteretic behaviour and the geometry of the structure to be examined, as well as on the definition of the dynamic excitations represented by acceleration time histories. These accelerograms must represent, on average, the hazard of the site under examination, commonly represented by an acceleration response spectrum. Usually the target response spectrum is defined, in a Probabilistic (PSHA) or Deterministic (DSHA) Seismic Hazard Assessment, through Ground Motion Prediction Equations (GMPEs). Therefore, ground motions should have magnitude, source distance and focal mechanism consistent with the sources that control the hazard at the site of interest. Moreover, site soil conditions and the possibility of experiencing near fault effects such as directivity and fling-step needs to be considered (NIST, 2011). Usually, acceleration time histories are selected from databases of records (e.g. the European Strong Motion (ESM) database (Luzi *et al.*, 2016) in order to satisfy all the above-mentioned characteristics and to match, over a defined range of periods, the target response spectrum. As the tolerance on the variability of the selection parameters becomes stronger, the lack of data becomes evident and some modifications (e.g. linear scaling) of the original recorded ground motions are needed if an adequate number of ground motion is to be used. A source of time histories could be the generation of artificial accelerograms (Gasparini and Vanmarke, 1976) or the use of the "response spectrum matching" technique (Al Atik and Abrahamson, 2010; Grant and Diaferia, 2013). However, these techniques have no physical meaning and there are concerns that their use could lead to biased results (Bazzurro and Luco, 2006; Iervolino *et al.*, 2010).

A viable alternative is to use synthetic accelerograms generated from a simulation of the source rupture and wave propagation. In this work, a direct link between hazard and response-history analysis is established. Synthetic seismograms are used to define the hazard as described by the Neo Deterministic Seismic Hazard Assessment (NDSHA) (Panza *et. al.*, 2001, 2012; Fasan *et al.*, 2016) and, as a logical consequence, to perform NLTHA on a selected building. A comparison of the results of NLTHAs obtained with natural and synthetic records confirms that physics-based simulations are a valuable tool in structural analysis. Moreover, the NDSHA method is applied to the site of Norcia and predicted spectral acceleration are compared with the recorded one during the event of the 30th of October 2016. Using NLTHAs, structural demands predicted using the real records and the synthetic ones used in the NDSHA are compared, showing that simulated accelerograms can be used to predict real non-linear demands of future earthquakes.

Method. Using the procedure proposed by Fasan *et al.* (2016), the so-called Maximum Credible Seismic Input (MCSI) has been defined at bedrock ($MCSI_{BD}$) for the site of Trieste (Fig. 1a). MCSI is a multi-scenario assessment and its computation briefly consists of (Fasan, 2017): identifying all the (known) sources that may affect the site of interest; assigning each source the maximum credible magnitude; performing physics-based computations considering variability by simulating different directivity, rupture velocity, distribution of slip on the fault plane and soil layers; identifying, at each structural vibrational period, the most hazardous source in terms of median spectral acceleration and developing the statistics of all simulated response spectra for the corresponding source (see Fig. 1a). Therefore, the controlling source (and the simulated accelerograms) can be different at each vibrational period, and a selection of accelerograms conducted by imposing the spectrum compatibility within a range of periods would involve different scenarios and sources. For each vibrational period, MCSI is set equal to the 95th percentile of the spectral accelerations and represents a sort of Uniform Hazard Spectrum (UHS). To each point of the MCSI "cloud" shown in Fig. 1a corresponds one accelerogram, therefore it is natural to use these accelerograms if it is needed to perform NLTHAs.

Using the MCSI (95th percentile) at bedrock ($MCSI_{BD}$) acceleration response spectrum, the 4-storeys Steel Moment Resisting Frame (S-MRF) shown in Fig. 1b has been designed according to EC8 (CEN, 2004). Only the 2D MRF along the x direction is analysed using time-history analysis. Interior columns have HE300B cross-section whereas that of the external ones is HE280B. The floor beams are IPE300, on the upper floor an IPE270 cross section is used instead. The length of the spans is of 6 m. The ground storey height is 4 m and 3.5 m in the others. This planar four storey steel MRF has a first vibrational period of 1.5 s with 85% of mass participation. Non-linear dynamic analyses are performed using the software ADAPTIC (Izzuddin, 1991) adopting a non-linear fibres model for the cross-sections and including large displacements effects. The steel material is class S235 as per EC8 and is modelled as bilinear with kinematic hardening. A direct-integration numerical analysis with the Newmark-β method is used to resolve the equation of motion adopting a Rayleigh proportional damping matrix. The constants α and β necessary to define the damping matrix are chosen to have a critical damping ratio of 1% at target periods of two times the first translational vibrational periods (3 s) and the fourth translation periods (0.17 s). This choice avoids a possible overdamping of short periods due to the matrix damping definition.

Five spectrum compatible sets of 11 recorded accelerograms are selected from the ESM database according to the following criteria dependent on the selected site: a magnitude range from 6 to 7; an epicentral distance range from 10 km to 30 km; EC8 soil class A or B; a period range for compatibility from 2 times the fundamental vibrational period T_1 to $0.2T_1$; a maximum deviation of spectral accelerations from the target spectrum ranging from 90% to 130% of the target value. No scaling is applied. The same criteria are adopted to select 5 sets of synthetic accelerograms from a database created for this purpose. As an example, a set of natural (NAT) and a set of synthetic (SIM) accelerograms are shown in Fig. 1d and Fig. 1e respectively; the other sets can be found in Fasan (2017).

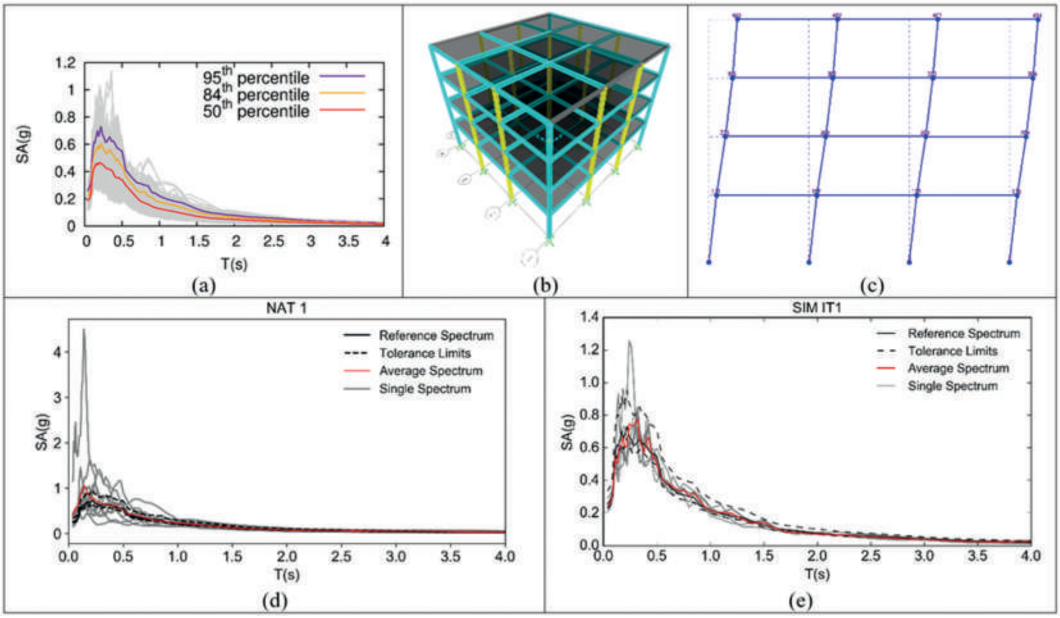

Fig. 1 - (a) $MCSI_{BD}$ computed at bedrock for the site of Trieste, (b) 3D S-MRF under analysis, (c) 2D analysed FEM model, (d) a set of spectrum-compatible natural response spectra, (e) a set of spectrum-compatible physics-based synthetic response spectra.

The 2D MRF along the x axis is extracted from the 3D model (Fig. 1c) and time-history analyses are performed using the selected sets. To understand whether the structural response obtained with the simulated accelerograms is comparable with that obtained with natural accelerograms, the mean values of different Engineering Demand Parameters (EDPs) resulting

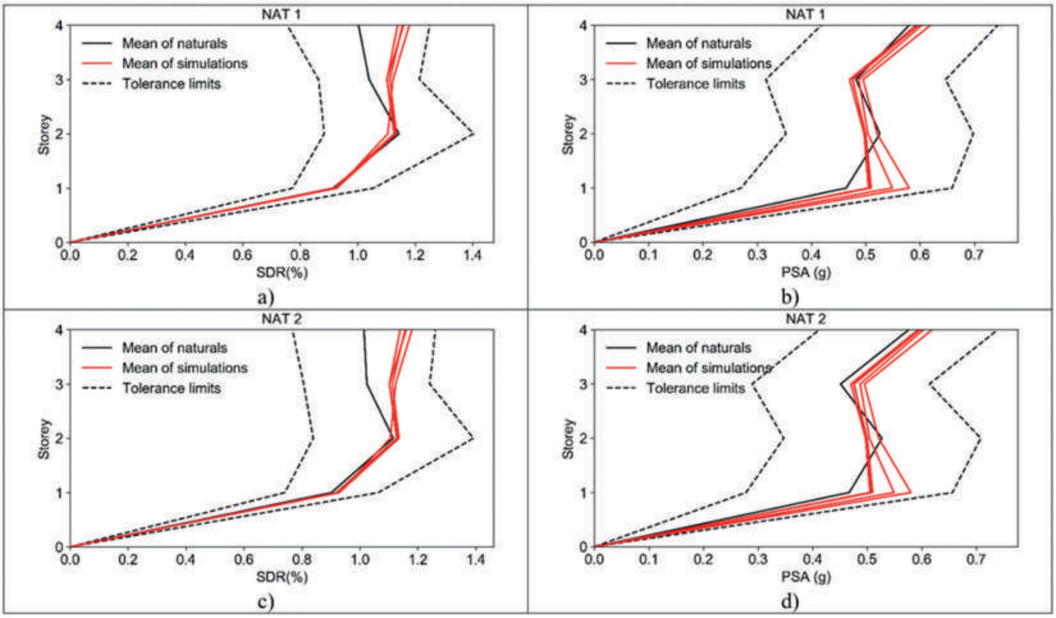

Fig. 2 – Comparisons between: (a) Inter-Storey Drift Ratio (SDR) NAT1-synthetics, (b) Peak Storey Acceleration NAT1-synthetics, (c) Inter-Storey Drift Ratio NAT2-synthetics, (d) Peak Storey Acceleration NAT2-synthetics

from each set are compared. Jayaram and Abrahamson (2012) and Bijelic *et al*. (2014) assumed that the difference between the sample mean of simulated and recorded accelerograms follows a normal distribution and that this difference is significant if it falls outside the range between the 2.5th and 97.5th percentile of this distribution. Here, a more stringent percentile range is used, namely from 16th to 84th percentile. In Fig. 2a to Fig. 2d comparisons between two sets of natural records (NAT1 and NAT2) and the five sets of synthetic accelerograms are shown adopting Inter-Storey Drift (SDR) and Peak Storey Acceleration (PSA) as EDPs. All tests give a positive result, confirming that there is no systematic difference between the two means. Hence, if used to look for maximum values of instantaneous parameters (as suggested by code-based procedures), NDSHA synthetic accelerograms provide reliable results.

A second test consists in the definition of the Site-Specific Maximum Credible Seismic Input ($MCSI_{SS}$) at the site of Norcia (NRC) and its comparison with results obtained with the records of the event of the 30th of October 2016 (Mw=6.5). Fig. 3a shows the calculated MCSI "cloud" (percentile from 5th to 95th) as reported in Fasan *et al*. (2016), along with a comparison with recorded spectral accelerations of the event. As it can be seen, MCSI spectral accelerations are really close to the recorded ones and site-dependent amplifications are well taken into account, meaning that NDSHA-MCSI can be a valuable tool to predict real accelerations of rare, yet possible, strong events. Similar results are obtained using the records of the events of 24 of August and 26 of October 2016 and can be found in Fasan (2017).

Synthetic accelerograms used to define MCSI are also used to perform NLTHA on the frame model introduced above. From all the accelerograms contributing to the definition of MCSI, 31 are selected to match the 95th MCSI percentile at the first vibrational period of the frame (T_1=1.5 s). The average acceleration response spectrum of these accelerograms is called Conditional-MCSI (Fasan, 2017) and is shown in Fig. 3b. This percentile was chosen because it is the value suggested to be used as a hazard target when using MCSI (see Fasan *et al*., 2015). Indeed, the aim is to verify if even in the non-linear field the expected demands using MCSI are consistent with those due to the real record. Fig. 3c and 3d shows the comparison between the structural demands (Inter Storey Drift and Peak Storey Acceleration) due to the records of the 30th of October 2016 and due to the synthetic records selected on the basis of the NDSHA-MCSI hazard assessment. The mean demands of the simulations are close to those from the real records, confirming that synthetic accelerograms used to define MCSI can also be used to run time history analysis of structures, allowing to capture site specific ground motion characteristics. The same tests reported in this section were also carried out on a 2-storey frame in order to investigate the possible influence of the structural periods, confirming what is reported here. Further tests are to be performed to check for cumulative parameters such as cumulative ductility, hysteretic energy dissipation or the equivalent number of yield cycles.

Conclusions. In this work, natural records are used to perform non-linear time history analysis on a selected steel Moment Resisting Frame. Results obtained with natural accelerograms are then compared with those obtained with different sets of NDSHA synthetic records selected in order to be consistent with the characteristics of the natural accelerograms following code-based instructions. These comparisons show that synthetic accelerograms selected to match any target response spectrum (both deterministic and probabilistic) provide structural demands that are equivalent to those obtained with natural records selected to match the same spectrum, at least when looking for maximum values of instantaneous parameters. A second test consists in using synthetic accelerograms to evaluate the Maximum Credible Seismic Input at the site of Norcia in the framework of the Neo Deterministic method. A comparison between MCSI acceleration response spectrum and the recorded spectral acceleration during the event of the 30th of October 2016 shows that the method well predicted the accelerations. Finally, a comparison between structural demands due to synthetic records selected following the Conditional Maximum Credible Seismic Input as proposed by Fasan (2017), and the demands due to the record of the 30th of October shows that this method also effectively predicted the structural demand. Hence,

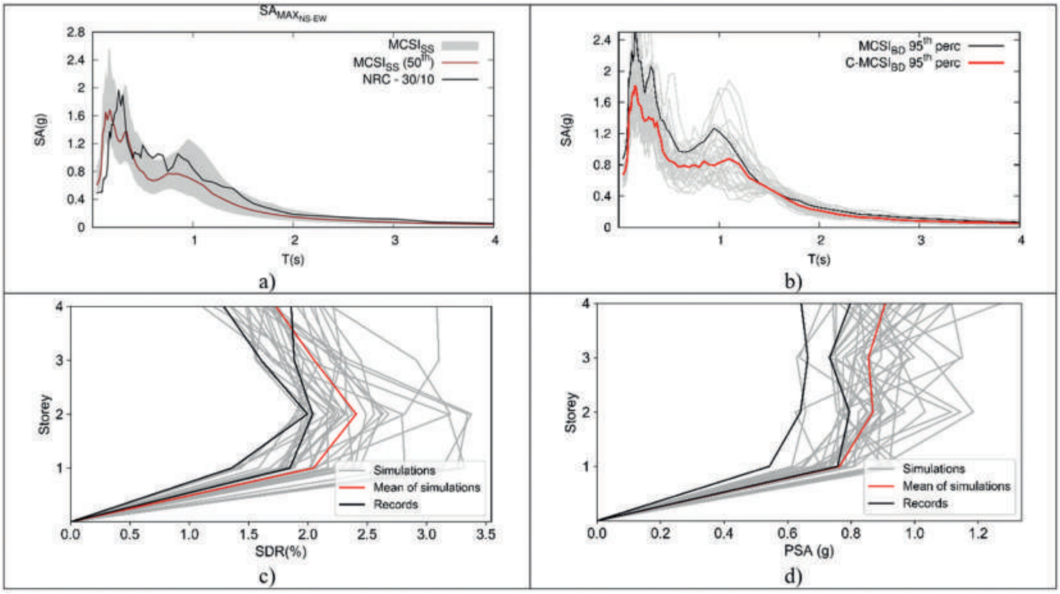

Fig. 3 - (a) Site-Specific MCSI computed at the site of Norcia (NRC), (b) set of selected synthetic response spectra and their mean value (C-MCSI), (c) Inter-Storey Drift Ratio comparison NRC record-synthetics, (d) Peak Storey Acceleration comparison NRC record-synthetics

on the basis of this work, NDSHA synthetic accelerograms seems to be a promising tool to estimate site specific seismic hazard and, consequently, to perform time history analysis with site specific input or for the selection of accelerograms compatible with any target response spectrum. Further testing are needed in order to generalize these results and take into account the cumulative non-linear structural demand.

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