Author's reply


The authors appreciate the valuable comments and insights from Dr. Moustafa concerning the important subject of the non-linear response of structures to earthquakes [1]. The numbered responses correspond to those in Dr. Moustafa’s discussion.

1. It is always difficult to judge the correct length of the literature review in a research paper, and the authors appreciate the additional literature review and references provided by Dr. Moustafa [1].

2. In our paper [2], the maximum deformation (i.e. the maximum top displacement) was used to highlight the large difference between earthquake records due to the disparity of energy distribution. Park and Ang [3] suggested the most popular damage index (DI) that included both the maximum deformation and the dissipated hysteretic energy. We agree with Dr. Moustafa that the dissipated hysteretic energy does play a very important role in measuring structural damage. We also used the DI to quantify damage for the ground motions used in our paper, and found that the results were identical to those obtained by using the maximum deformation. The explanation is that for the examples considered the maximum deformation caused by the concentrated energy dominated the DI. In addition, the DI measures the damage of an element, and to assess the global damage of a structure based on the DI is difficult because there are no accepted models to integrate the element DI’s into a global damage measure. Thus, we used the maximum deformation in our paper due to its simplicity. However, the DI could be used in our future work to determine appropriate weights for evaluating the CPGA.

3. The additional references provided by Dr. Moustafa are valuable. Indeed one of Priestly’s earlier papers [4] was used to understand the energy evolution of non-stationary random processes.

4. In the code for seismic design of buildings (the seismic code of China), PGAs are stipulated for acceleration histories (either recorded or artificial) used for elastic or nonlinear time-history analysis of structures. The specified PGAs are given according to the seismic zone in which structures are located. So the selected records in our paper are normalized in terms of the PGAs, i.e. 4, 6.2 and 5.3 m/s² for frames 1, 2 and 3, respectively. Of course other normalizations of the records, such as the Arias intensity, could also be used depending on the situation analyzed.

5. All three frames were designed using the code for seismic design of buildings, the code for design of concrete structures and the technical specification for concrete structures of tall building. They are codes for China. The technical specification is for tall concrete structures including their seismic design, which classifies a building as tall if its height is at least 28 m, or has 10 or more stories, although the specification is also used for buildings slightly under 28 m in height. However the specification does not include the seismic zone division and the site classification. In our paper, frame 3 is within the definition of a tall building, while the heights of frames 1 and 2 are just a little low. For consistency the codes and specification were used for the design of all three frames. For frame 1, the superimposed loads were 30 and 24 kN/m for the floor beams and the roof beams, respectively, taking into account the dead load, the live load and the infill load. The nonlinear time-history analysis was performed by OpenSees, where the fiber model for concrete and steel was used and the material characteristics are given in our response to point 7.

6. The records were chosen based on the seismic code of China, rather than the selection strategy by Bommer and co-workers. Thus the selection criteria were based on the SNARS (standard normalized acceleration response spectrum) and the duration. The code does not have any explicit criteria for the earthquake magnitude, epicenter distance and local soil type beneath the structure. There is some interpretation required for the definition of near-field and far-field (also termed near-fault and far-fault). Bray and Rodriguez-Marek [5] defined the near-fault zone typically to be restricted to within a distance of about 20 km from the ruptured fault. While Chopra and Chintanapakdee [6] implicitly state that a near-fault record is one where the epicenter distance is within 10 km. If the requirements of earthquake magnitude, epicenter distance and local soil type are added to the SNARS criteria, finding adequate eligible records will be very difficult. The method usually adopted in China is to choose a record randomly from the library and compare its normalized acceleration response spectrum with the SNARS. The chosen records are then normalized by the specified PGA according to the seismic zone. Also stipulated in the seismic code of China, the input for structural dynamic analysis are at least two real records and one artificial acceleration history, with a duration of 5–10 times the fundamental period of the analyzed structure.

7. The excursion in the displacement history is not necessarily the best method to judge whether a multi-degree-of-freedom structure behaves inelastically. The PGA of the records for frame 1 is 4 m/s², and for frames 2 and 3 are 6.2 and 5.3 m/s², respectively. These PGAs represent major earthquakes in the seismic zones where the frames are located, and are larger than the PGAs used by Wang (Ref. [8] in our original paper). The frames were designed for strength capacity based on minor earthquakes within the seismic zones. The material for
concrete (the core concrete, i.e. the concrete confined by the stirrups) and longitudinal steel of the beams and columns are uniaxial Material Concrete01 and uniaxial Material Steel02, respectively, in the nonlinear analysis program OpenSees. The maximum and crushing compressive strengths for the concrete were 28.7 and 5.7 N/mm², respectively, with corresponding strains of 0.0018 and 0.011. The yield strength for the longitudinal steel was 388 N/mm², with the initial elastic tangent and stain-hardening ratio being \( 2 \times 10^5 \) N/mm² and 0.01, respectively. Thus the frames will behave inelastically when excited by the given records. Cao et al. [7] showed the plastic hinges in beams and columns graphically and demonstrated that the frames were indeed behaving inelastically.

Erratum

1. On page 293, below Eq. (1), “the scale parameter a to be sampled in dyadic form, which guarantees the orthogonality of wavelets” should be corrected to “the scale m is given by a set of integers”.

2. The title of Ref. [7] should be corrected to “Effects of earthquake frequency nonstationarity on inelastic structural response”.

3. On page 297, the last sentence “The seismic fortification grade is I for frame 2 (which is higher than that of frame (1) and II for frame 3’’ should be corrected to “The seismic fortification grade is I for frame 2 (which is higher than that for frame 1) and II for frame 3’’.

References


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