Seismic response of complex structural systems using code-compatible as-recorded and simulated ground motions

Vahid Loghman[1], Karim Tarbali[1], Brendon Bradley[1], Reagan Chandramohan[1], Chris McGann[1], Didier Pettinga[2]

[1]Department of Civil and Natural Resources Engineering, University of Canterbury; [2]Holmes Consulting Group

QuakeCoRE NZ Centre for Earthquake Resilience

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

1. Motivation

Response History Analysis (RHA) is an advanced method for investigating the dynamic behavior of structural systems for seismic design and performance assessment.

- Simulated Ground Motions (GMs) are considered as a supplement to the ensembles of recorded GMs in seismic RHA, specifically for large magnitude near-fault ruptures where there is a scarcity in the database.
- Validation of simulated GMs is essential to investigate the validity and applicability of the simulation methods in generating inputs for engineering demand analysis.

The validation matrix (Bradley et al. 2017) illustrates the importance of validation in order to develop predictive confidence in simulated GMs (Figure 1).

- The horizontal axis indicates the increase in complexity of intensity measure metrics used in quantifying simulation validation.
- Particularly, the fourth column indicates the use of complex system responses to validate simulated GMs.

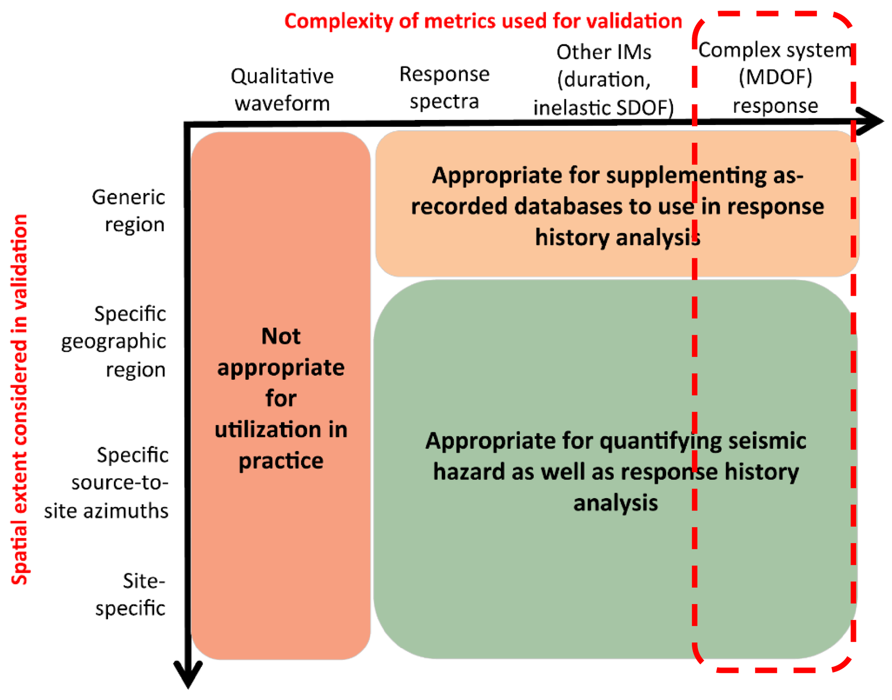

Figure 1: Validation matrix for ground motion simulation (Bradley et al. 2017).

The aim of this poster is to examine the seismic response of two real complex structural systems when subjected to ground motions for the 22 February 2011 Christchurch earthquake – both those observed at strong motion stations and also simulated at the same locations as documented in Razafindrakoto et al. (2018).

2. Building Properties

Two buildings that have been designed and physically constructed in Christchurch based on NZ standards are considered. The 3D model used for nonlinear response history analysis is created by consulting engineers for the design of the system (Figure 2a).

- **Building A** is a six-story Reinforced Concrete (RC) with a moment resisting frames in both directions, plus boundary wall system in the North-South and shear walls in the East-West direction. Also, a lightweight story has been added to the roof. The fundamental period of buildings A is 0.5 sec.
- **Building B** is a thirteen-story with ductile RC walls in the East-West direction and ductile RC coupled walls in the North-South direction. The fundamental period of building B is 2.0 sec.
- **Nonlinear elements:** The model uses lumped plasticity elements for beams and columns. Wall elements have effective fibre-models. Coupling beam elements are defined with an equivalent reinforcing content to capture their capacity and backbone derived from FEMA coupling beam with diagonal reinforcement. Shear walls are modelled using the FEMA "Concrete Shear Wall Segment" definitions. Figure 2b shows the general nonlinear model of the concrete elements (FEMA 356).

a) Building A **Building B** **b)**

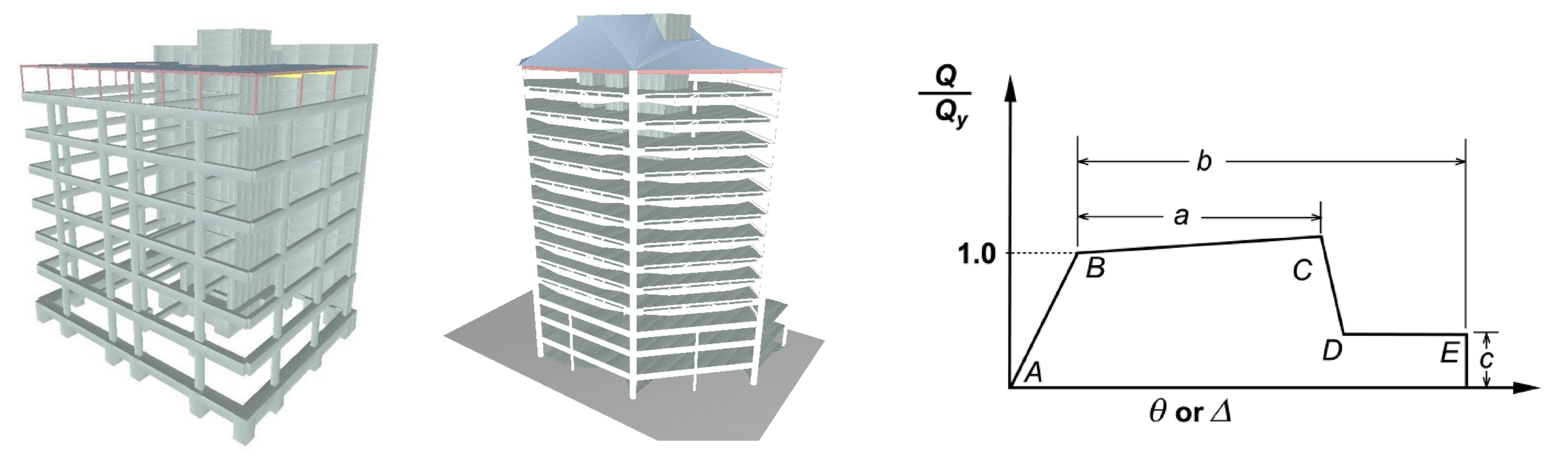

Figure 2: a) 3D View of Building A and B. b) Nonlinear model of concrete elements (FEMA356).

3. Simulated and as-recorded Ground Motion (GM) Properties

The selected buildings are analysed subjected to simulated and observed GMs from 40 stations of 22 Feb. 2011 Christchurch Earthquake (Figure 4a-b).

- Simulation is done by the hybrid broadband method developed by Graves and Pitarka (2010, 2015). The GMs are scaled following the NZS1170.5 procedure. the medians of scaled observed and simulated GMs are shown in the period range suggested by NZS1170.5 for Building A and B, respectively (Figure 4c-d).
- The median of observed GMs is greater than the simulated ones outside the scaling region for Building A (Figure 4c-d). This indicates the greater intensity of observed GMs in the mentioned region, which can affect the responses of Building A due to period elongation when the structure experiences nonlinearity. In contrast, the medians are well matched in and after the scaling range for Building B.

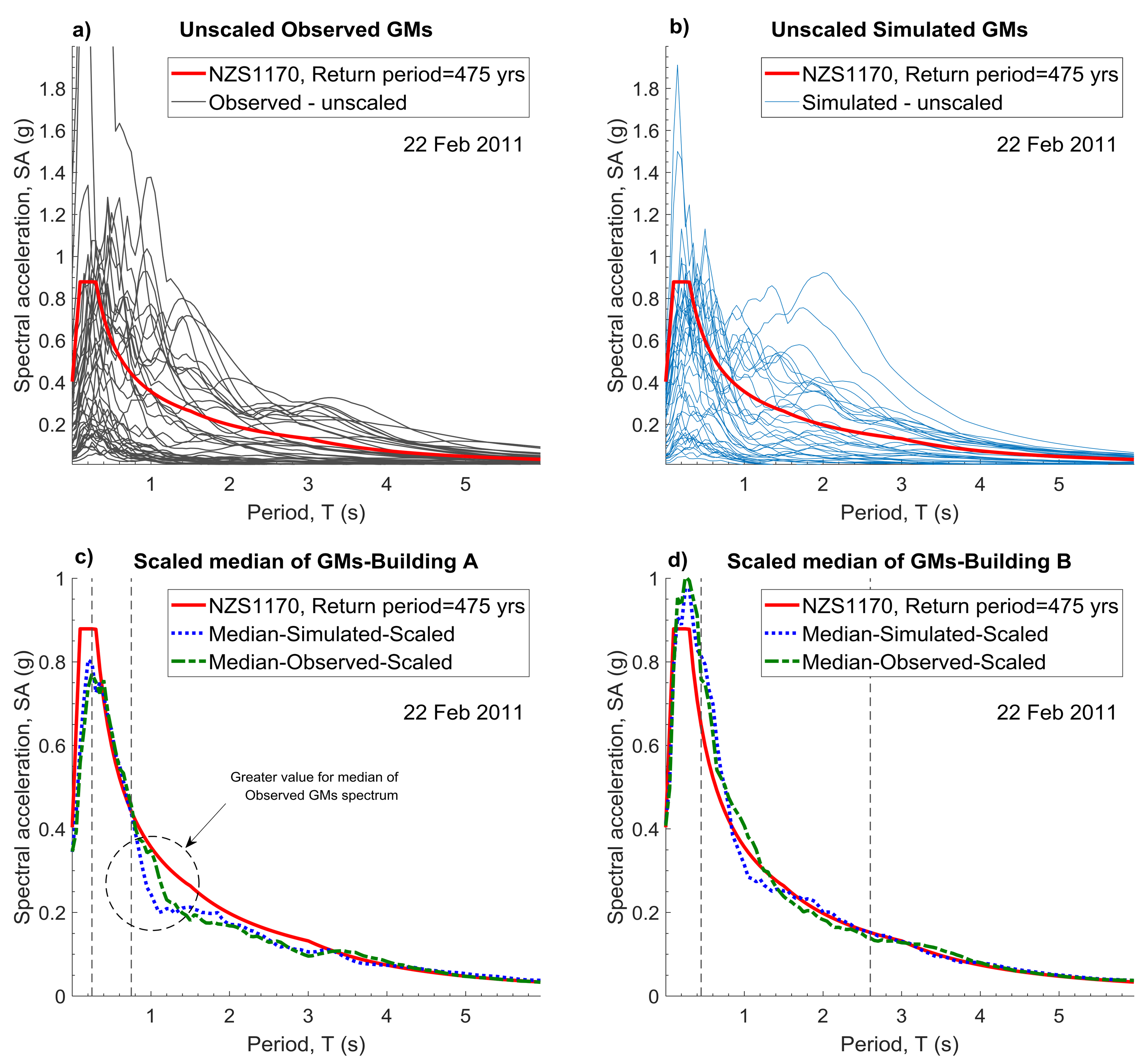

Figure 4: a-b) Unscaled response spectra of observed and simulated GMs c-d) median of scaled ground motions for Building A and B

4. Comparison between Engineering Demand Parameters (EDPs)

Seismic responses of buildings A and B are compared when they are subjected to scaled simulated and observed GMs. Figure 5 shows the ratio of simulated to observed responses in the centre of mass along the height of the buildings. In this figure, the geometric mean and the 16th and 84th percentiles of the responses are shown. The red line shows unity, indicating the same responses from simulated and observed ground motions.

- Inter-story Drift Ratio (IDR) and Peak Floor Acceleration (PFA) are selected as the main responses.
- An under-prediction in the responses of Building A, specially IDR (Figure 5a-b).
- A good agreement between the simulated and observed responses of Building B (Figure 5c-d).

Building A

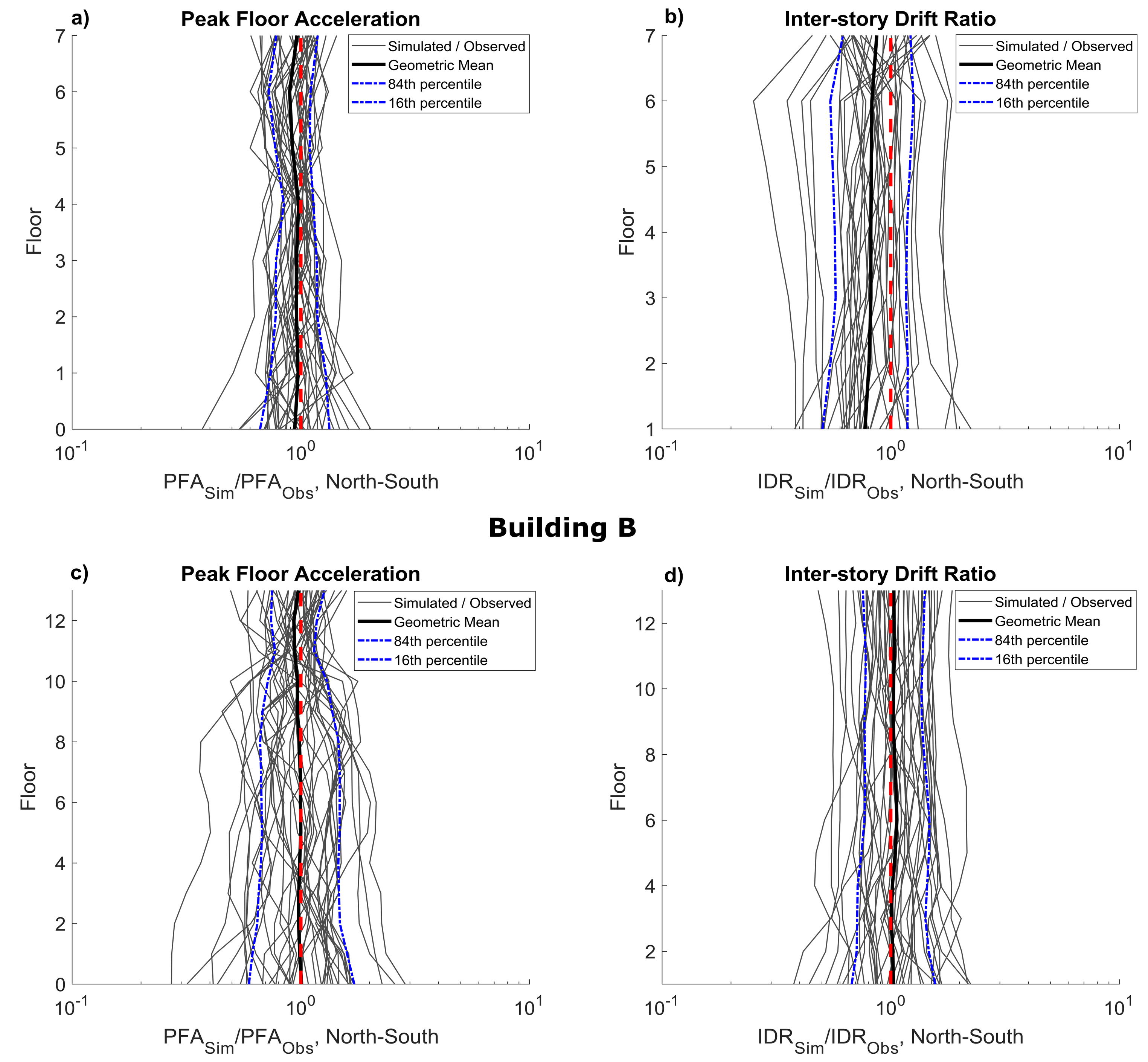

Figure 5: The ratios, geometric mean and percentiles of simulated to observed responses a-b) Building A accel. and drift; c-d) Building B accel. and drift.

5. Comparing EDP variability due to record-to-record variability

Herein, the differences between the responses of observed and simulated GMs are assessed to determine whether these variations inherently exist in the two groups of responses, or they are due to the finite amount of data in the analyses. Bootstrap sampling technique and hypothesis testing are utilized to investigate whether the differences are statistically significant.

- Calculating p-values demonstrate the statistically significant difference between responses for Building A IDR, while there is no statistically significant difference for Building A PFA, Building B PFA and IDR (Figure 6a-d).

Building A

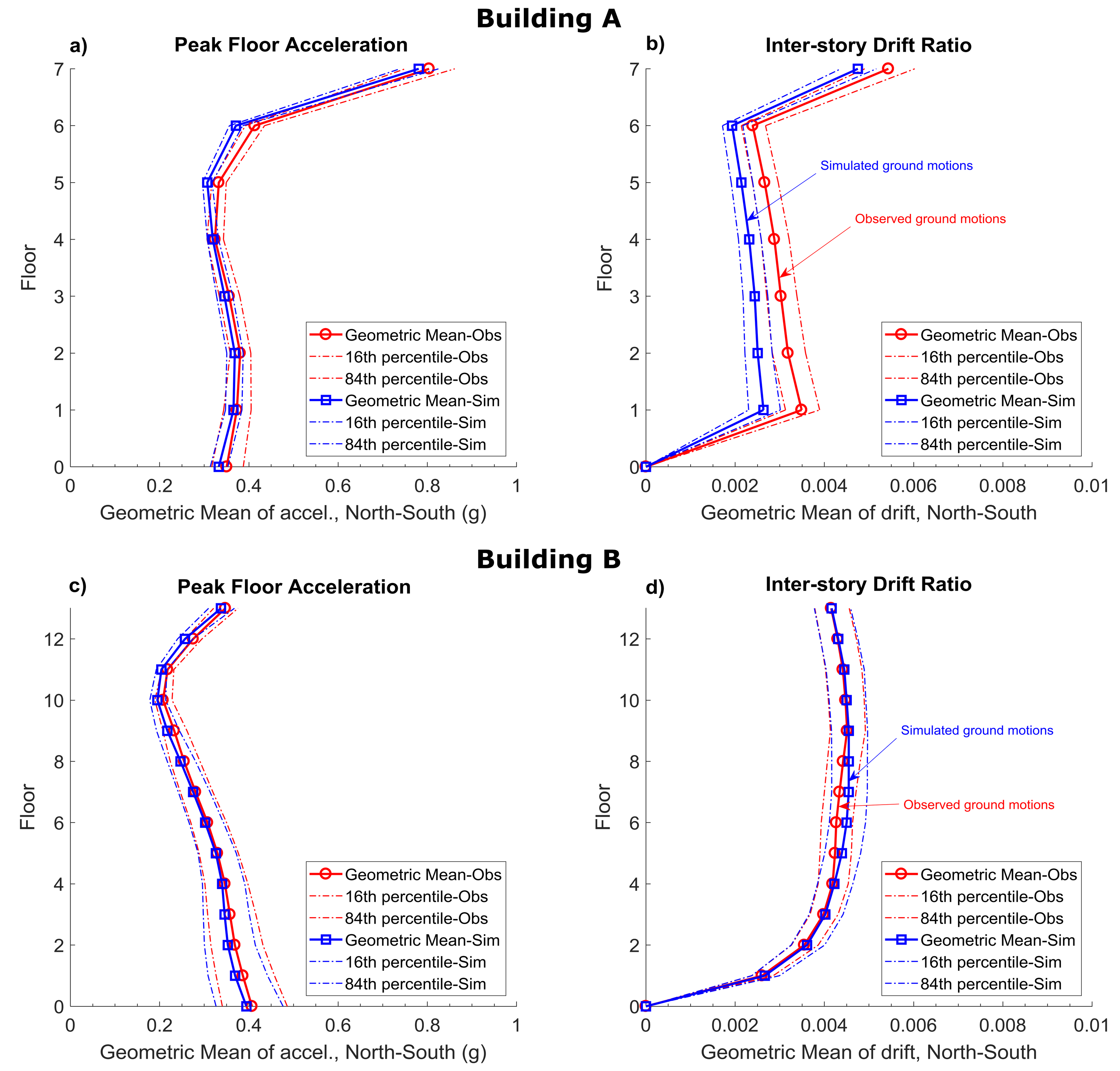

Figure 6: Geometric mean and percentiles of bootstrapped samples a-b) Building A accel. and drift; c-d) Building B accel. and drift.

6. Conclusion

Validation of simulated ground motion is considered by comparing responses of 3D structural models subjected to scaled as-recorded and simulated GMs. The models represent real buildings, which have been designed based on the NZS1170.5 and physically constructed before Canterbury earthquake sequences. Attempts are made to investigate the similarities and discrepancies between the responses of the system excited by observed and simulated GMs when the code instructions are followed in the analysis and design. The results indicate a general agreement between the Peak Floor Acceleration (PFA) calculated by the simulated and recorded ground motions for two buildings. According to the hypothesis tests results, the differences in Inter-story Drift Ratio (IDR) are significant for the building with the shorter period and can potentially be attributed to greater value for the median of observed spectrum.