Seismic hazard analysis and ground motion selection considering directivity effects

Karim Tarbali [1]*, Brendon A. Bradley [1], Jack W. Baker [2]

[1] University of Canterbury; [2] Stanford University

* karim.tarbali@pg.canterbury.ac.nz

Stanford ENGINEERING Civil & Environmental Engineering

QuakeCoRE NZ Centre for Earthquake Resilience

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

1. Background and Objective

Selecting appropriate ground motion ensembles is a key step in assessing the seismic performance of engineered systems through time-domain seismic response analyses. Recent developments in earthquake rupture forecast and ground motion models (GMMs) provide the engineering community with advanced empirical models to consider physical processes such as rupture directivity in seismic hazard calculations.

This study presents an example application of such models to assess the seismic hazard in the near-fault region and subsequently select ground motion ensembles that appropriately represent the target hazard. Implications of the variability in the selected ground motion characteristics are discussed in terms of the demand hazard and collapse fragility.

2. Considering forward directivity pulses in seismic hazard analysis

2.1. Scenario seismic hazard analysis

Conventional GMMs do not explicitly account for the characteristics of near-fault ground motions such as directivity velocity pulses. The method used in this study to consider directivity effects is a post hoc correction model based on Shahi and Baker (2011), considering:

- Multiple realizations of hypocentre for a given rupture.
- Full distribution of pulse period given rupture magnitude (M_w).

Figure 1 illustrates percentiles of the predicted spectral acceleration (SA) ordinates for a $M_w = 7$, $R_{rup} = 5$ km scenario rupture with $V_{s30} = 400$ m/s based on the Boore and Atkinson (2008) GMM, with and without explicit modification for directivity effects. Note the increase in the target SA for the range of vibration periods consistent with the pulse period distribution predicted for the corresponding rupture (i.e., $T = 1 - 7s$).

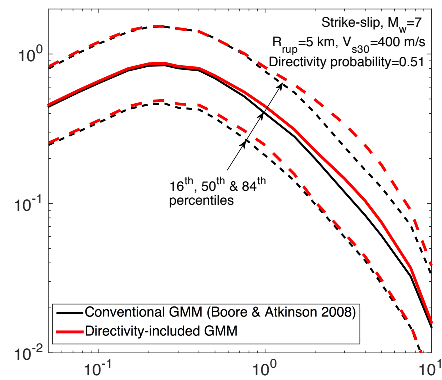

Figure 1: Increase in long-period SA ordinates due to directivity effects.

2.2. Probabilistic seismic hazard analysis

Figure 2(a) compares the hazard curve for Los Angeles with and without considering directivity effects for $T = 3\,s$ SA. As shown, considering directivity effects results in a 11% and 18% increase in the ground motion level for 10% and 2% in 50 years exceedance probabilities (EPs), respectively.

Figure 2(b)-(c) compares the contribution of the causative ruptures in the vicinity of Los Angeles for SA(3.0 s) hazard at 2% in 50 years EP. As shown, considering directivity effects increases the contribution of the nearby sources that have a favourable source-to-site geometry (i.e., high probability) for directivity pulses.

The reason for the difference in the directivity effects across different EPs, sites, and IMs is the difference in the characteristics of the contributing ruptures, including the rupture magnitude and its occurrence probability, in addition to directivity probability related to the source-to-site geometry.

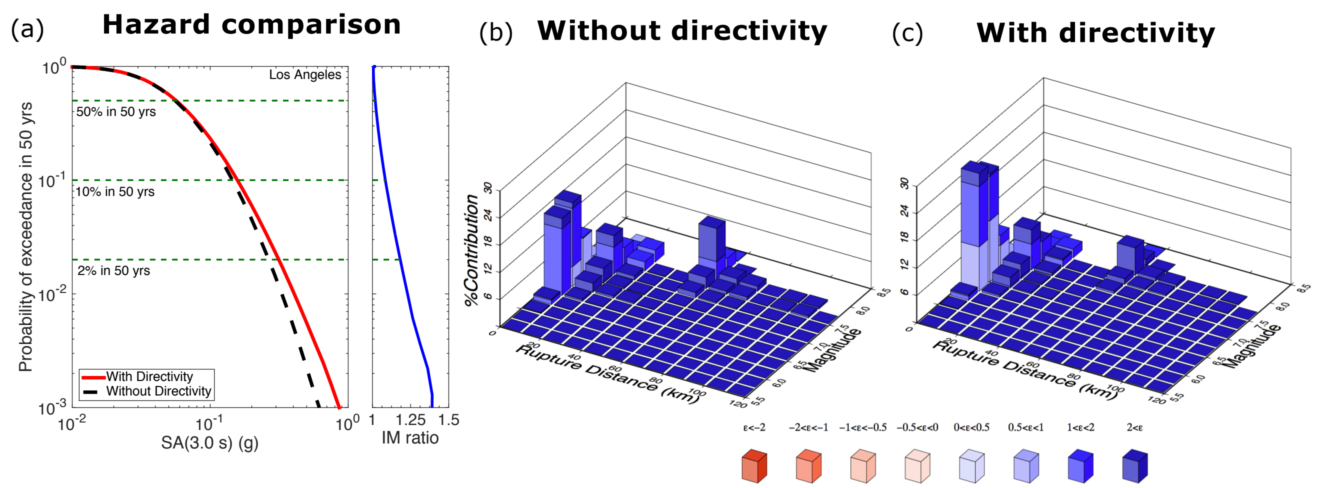

Figure 2: (a) SA(3.0 s) hazard curves; and (b)-(c) deaggregation results for Los Angeles at 2% in 50 years EP, with and without considering directivity effects.

3. Ground motion selection

A holistic approach for selecting ground motion ensembles (based on the GCIM methodology) incorporates the variability in the estimated ground motion and considers multiple IMs representing amplitude, frequency content, and duration of motion. Figure 3 illustrates the 5-75% significant distribution (D_{s575}) and response spectrum targets for ground motion selection, conditioned on the SA(3.0 s) hazard at 2% EP for Los Angeles. As shown, considering directivity effects results in changes in the IM distribution, due to:

- Change in the conditioning IM value, shown in Figure 2(a).
- Change in the contribution of causative ruptures, shown in Figure 2(b)-(c).

Note the increase in the short-period SA ordinates due to considering the contribution of all causative ruptures, instead of a single scenario rupture.

Also, note the reduction in the median significant duration due to the consideration of directivity effects.

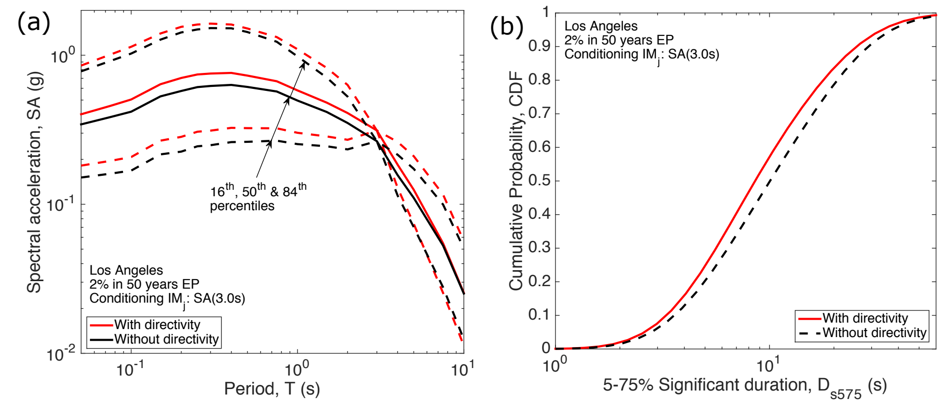

Figure 3: Directivity pulse effects on the target IM distributions for ground motion selection.

Figure 4(a)-(c) presents the SA ordinates, D_{s575}, and pulse period distributions of the selected ground motions representing the SA(3.0 s) hazard at 2% EP for Los Angeles. As shown, selection based on an appropriate set of IMs (i.e., SA and non-SA) leads to a ground motion ensemble with an appropriate representation of the directivity-included target hazard in terms of explicit IMs, and also implicit measures such as pulse period, which are themselves affected by any forward directivity effects.

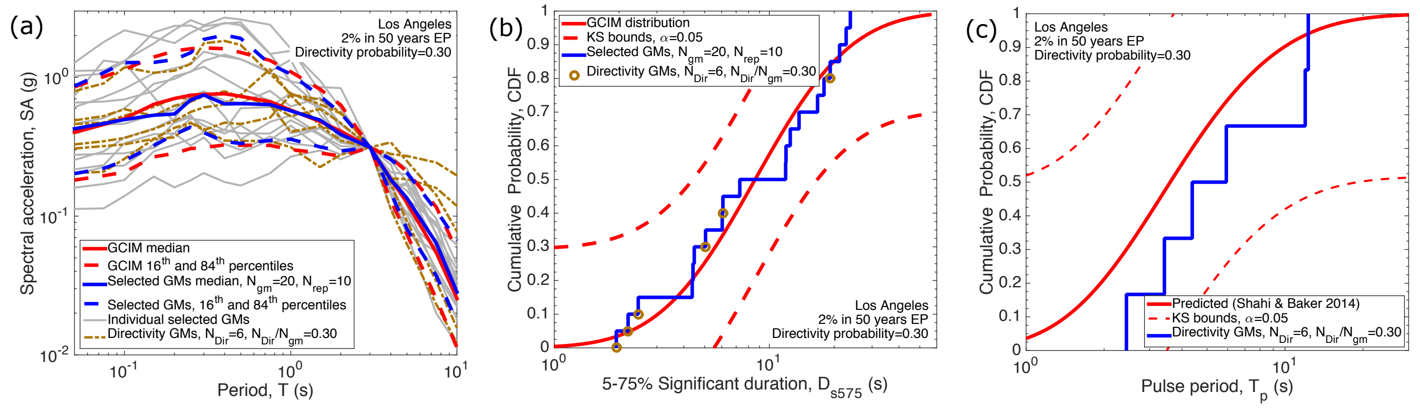

Figure 4: Selected ground motions properties representing the directivity-included target hazard.

4. Impact in probabilistic seismic performance assessment

Selected ground motion ensembles are used to assess the demand-based seismic performance of degrading inelastic SDOF systems. Figure 5(a)-(b) presents the collapse fragility and demand hazard curves calculated based on 20 replicate ground motion ensembles in order to investigate the effect of record-to-record variability. As shown, a variation in the collapse probability results in a large variation in the near-collapse demand hazard.

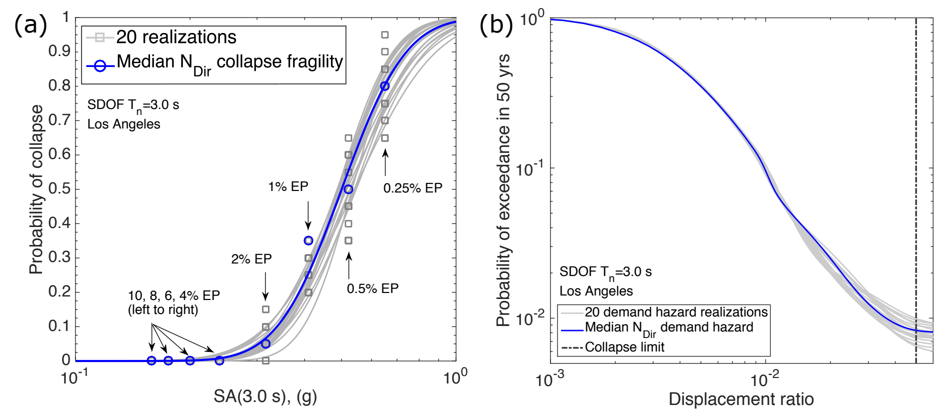

Figure 5: (a) Collapse fragility; (b) demand hazard.