2014 SCEC Project Report: Proxy metrics for ground motion simulation validation—fling parameters

Jack W. Baker

Abstract:

In this study, we identified data sources for static fling in ground motions, compiled a dataset of ground motions containing fling, extracted fling parameters from these ground motions, and derived a predictive model for fling period and amplitude that is compared to existing models. We found that ground motion simulations provided a rich and reliable data source for fling step, indicating an additional engineering use case for simulations. The work also validated the ability of simulations (specifically those of Aagard in this study) to predict fling in conditions not well captured by empirical data sources.

Intellectual merit

This work has investigated and demonstrated the validity of another dimension of ground motion simulations—namely the ability of simulations to capture the static and dynamic effects of fling in earthquakes. This is a property that is poorly constrained by empirical data sources such as strong motion accelerograms or high-rate GPS, and so provides unique information for engineering applications sensitive to static offsets during potential future earthquakes. Our technique for rapidly extracting fling step from millions of simulated time histories is novel, and our efforts to validate the extracted features versus empirical data also provided new insights in this area.

Broader impacts

This project provided partial financial support for PhD student Lynne Burks to finish her degree, and to travel to the 2014 SCEC annual meeting to present her research. The findings from the work have been cited in discussions of the ASCE 7 building code Provisions Update Committee, where there were concerns raised about the potential effects of static offsets on structures, and whether current analysis procedures were sufficient to assess these effects. The work has thus had some impact on the procedures that will be used to design future buildings in the United States.

Project Report

This work studied statistical properties of a "proxy" structural response metric, which is an indicator of the behavior of more complex structural engineering systems. Proxy metrics serve an important role in validation of ground motion simulations, because they are simple and amenable to validation, but good indicators of the response of other systems for which validation may not have been performed. The PI's recent work has focused on statistics of elastic and inelastic response spectra from simulated ground motions, given their importance to engineering design, and compared observed properties to comparable results from recorded ground motions. This proposal extended that work to consider static fling in ground motions—a feature not well represented in recorded ground motions, meaning that simulations play a valuable role in situations where fling has an impact on the structural demands.

The novelty of this work is in the use of proxy metrics that are important for engineering purposes, less well studied than some other spectral properties, but known to be relatively stable across a range of earthquake scenarios so that the "correct" answer is relatively well defined over a range of conditions. Validation has been performed by many ground motion simulators in the past (e.g., Aagaard et al. 2010; Archuleta et al. 2003; Bazzurro et al. 2004; Mai and Beroza 2003; Olsen and Mayhew 2010; Galasso et al. 2013 among many others). This project supplements those studies by considering properties of ground motions that have not received significant attention in the past but that are nonetheless known to affect the response of structures. A common method for validating simulated ground motions is to compare the means and standard deviations of response spectra from simulations to the equivalent results observed from empirical ground motions, as quantified by comparable recordings or ground motion prediction models (e.g., Abrahamson et al. 2008). An additional important calculation, which has not been as widely performed with simulated ground motions, is to compare the correlation between response spectral values at multiple periods and orientations: features that have been shown to be an important factor affecting structural response (Burks and Baker 2014a). This proposal performed additional evaluations of potential proxy metrics.

We investigated fling parameters as a potential validation metric. Fling is caused by a permanent static offset of the ground and is strongest for strike-slip faults in the fault parallel direction. While near-fault directivity has received much attention from structural engineers, fling has been largely ignored because static offsets are typically filtered out of ground motion records before being used for engineering analysis. Raw seismograms recorded from earthquakes contain errors due to noise and baseline offsets from tilting and transducer response to strong shaking. Analysts typically address this by processing ground motion records using filtering and baseline correction (Figure 1), but because the amplitude of the static offset is highly sensitive to the choice of baseline. making them difficult to use as a data source for quantifying fling.

Simulations, on the other hand, provide a valuable potential data source for fling effects, as this is a low-frequency phenomenon well-captured by some deterministic simulation techniques. We evaluated ground motion simulations to evaluate their usability for quantifying fling effects. We evaluateed the reasonableness of observed fling effects in terms of parameters for fling period and amplitude, relative to theoretical predictions and the limited available empirical models (e.g., Abrahamson 2002). Figure 2 shows fling period predictions from a number of data sets and predictive models. While there is wide scatter in the periods associated with a particular time history, the simulated ground motions were found to be in good agreement with other benchmark data and models. Figure 3 shows comparable results but for fling amplitudes. Again there was good agreement with empirical data and models. The simulations, however, obviously have much greater resolution in identifying spatial correlation of amplitudes, and the effect of buried versus surface ruptures on displacements. These results are currently in review as a journal paper (Burks and Baker 2015).

Additionally, we performed collapse capacity assessments of engineering structures, under ground shaking with and without fling effects, to quantify the importance of capturing this phenomenon when performing engineering analyses. An example of such an analysis, using a recorded ground motion with fling and a structural model capturing collapse, is shown in Figure 4. Under conditions when fling effects are important for engineering analysis, simulations are an important resource and so this benefit should be communicated to the engineering community. These results were recently published in a conference proceedings (Burks and Baker 2014b).

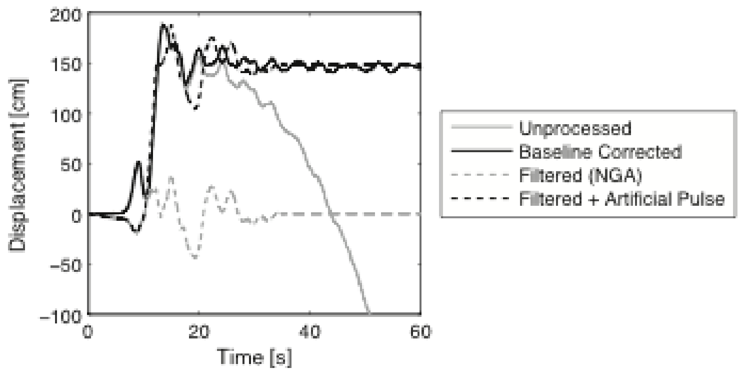

Figure 1: Multiple versions of the displacement time history from the YPT station in the 1999 Kocaeli, Turkey earthquake, including unprocessed, baseline corrected, filtered (from NGA database), and filtered plus an artificial fling pulse.

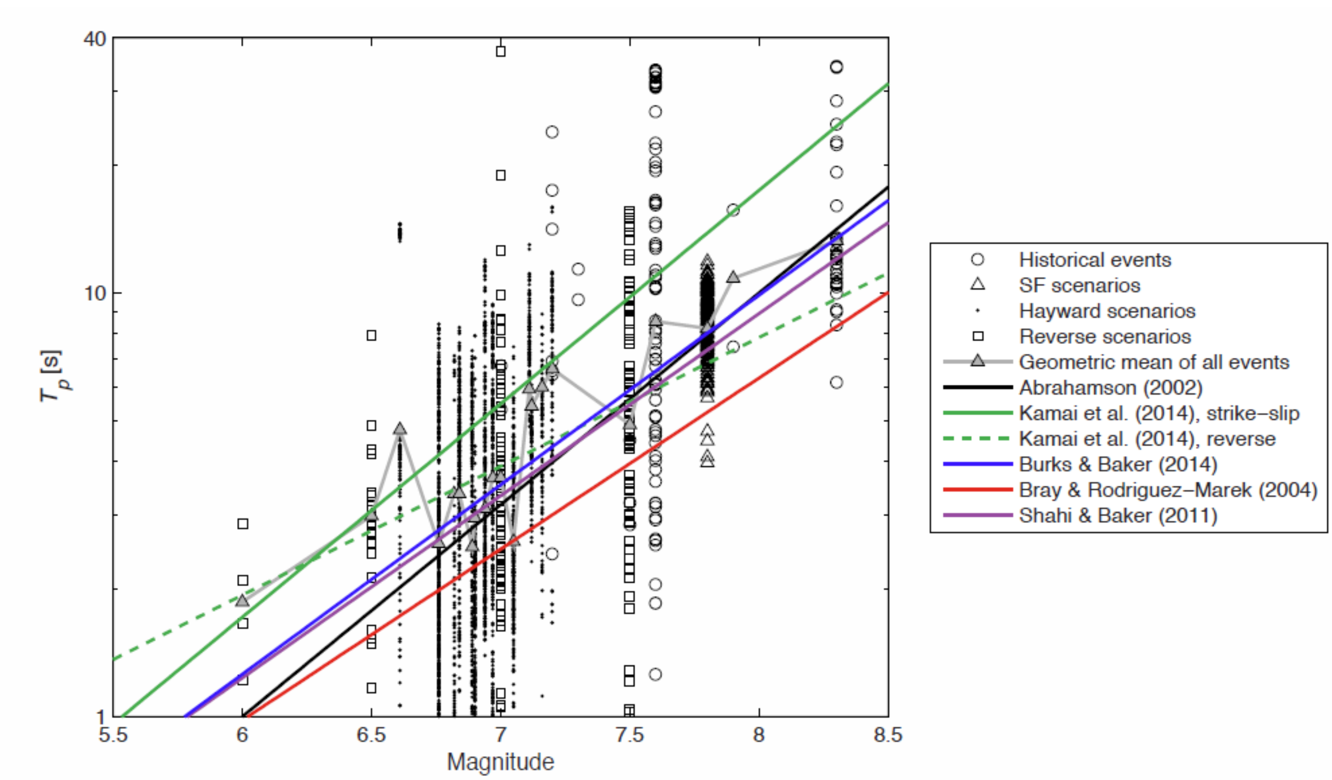

Figure 2: Observed fling periods from simulations, observations and predictive models.

M = 7.8 data comes from Aagard San Francisco scenarios, M = 6.76 comes from a subset of Aagard Hayward scenarios, M = 7.0 data comes from BroadBand Platform reverse scenarios, and M = 7.6 comes from Chi-Chi recordings.

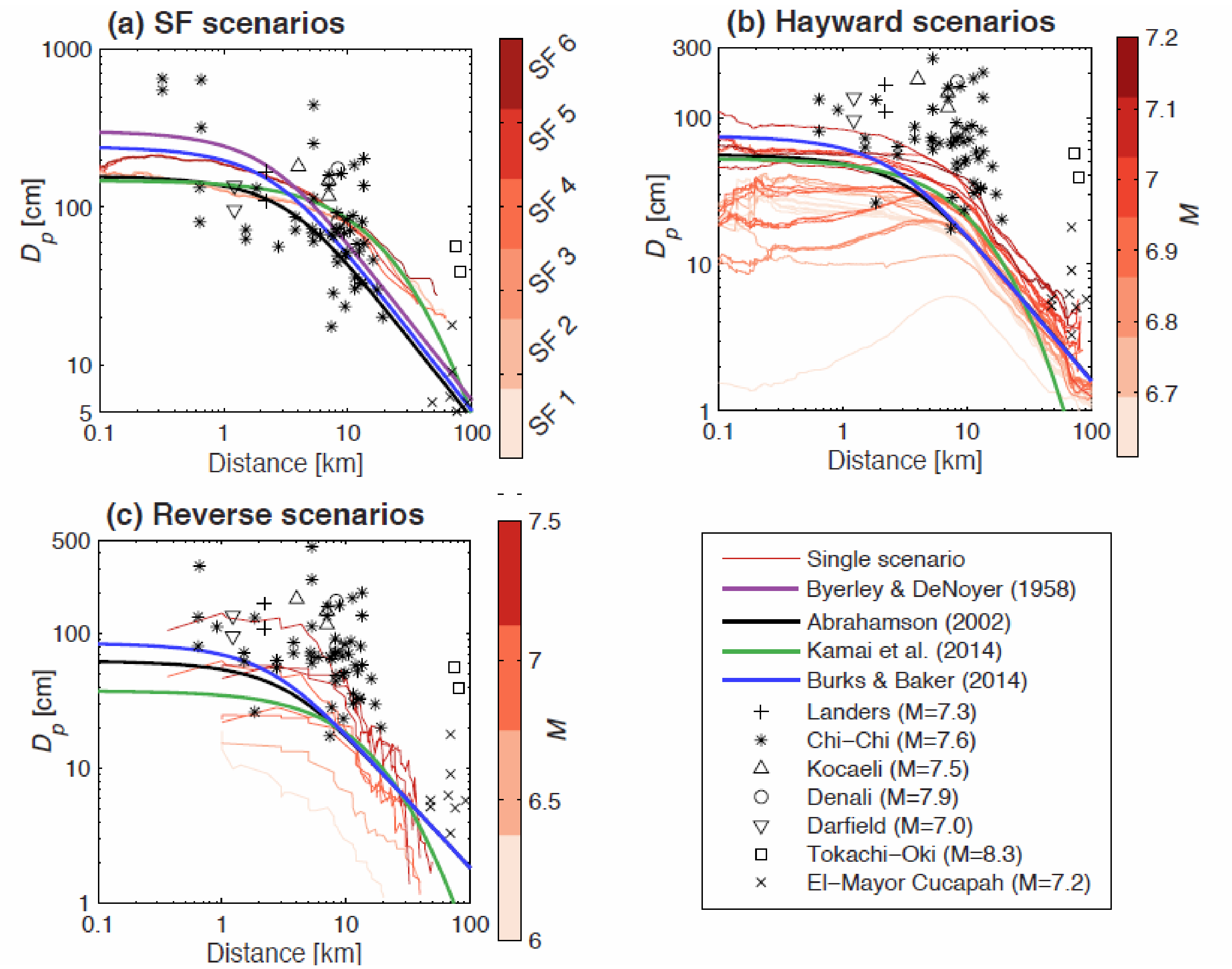

Figure 3: Comparisons of fling displacement amplitudes from simulations, recordings, and predictive models. The smoothed average of fling amplitude for each scenario is compared to relevant empirical models and results from recordings. Each "single scenario" line represents the average fling amplitude of all simulated ground motions in one earthquake scenario as a function of closest distance to the fault. We also compare the average and maximum surface displacement along the fault for each scenario to empirical models.

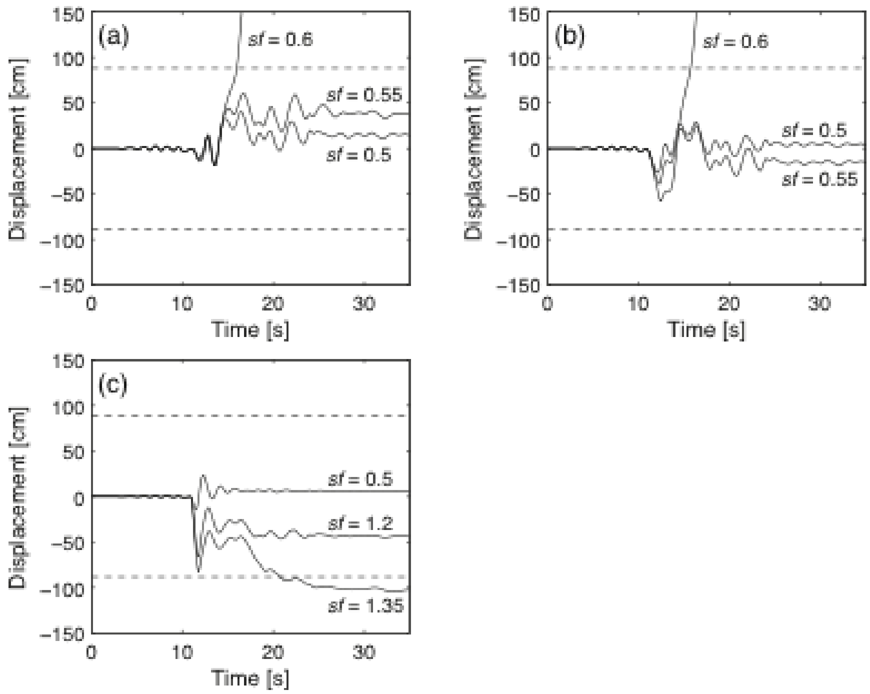

Figure 4. Displacement response of an example structure to multiple versions of the TCU068 Chi-Chi, Taiwan ground motion record scaled at different factors (where *sf* is the scale factor), including (a) the NGA version, (b) pulse *C* with D_p = 375 cm added to the NGA version, and (c) pulse *C* with T_p = 1 s added to the NGA version. Collapse occurs when the displacement of exceeds the structure's ultimate capacity as represented by the dashed line (figure from Burks and Baker 2014b).

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