USGS Workshop on Seismic Directivity:

Implementation within the National Seismic Hazard Model

Day 1: Introduction

Withers/Shumway (kwithers@usgs.gov)

Withers and Shumway will provide greetings and an introduction to the workshop, as well as provide details on logistics of Team's features and how to use the various technical options, including asking questions and posting comments.

Petersen (mpetersen@usgs.gov)

Petersen will go over the 2023 NSHM Plan, including timelines, consideration of new models, and feedback from developers, as well as provide context for implementation of directivity models into the NSHM.

Withers (kwithers@usgs.gov)

Withers will provide an outline of the workshop schedule and discuss the workshop goals.

Day 1: Overview of Seismic Directivity Models

Overview of the Bayless model (jeff.bayless@aecom.com)

This presentation will cover recent updates to the Bayless et. al. model, example applications, and future steps.

A Comprehensive and Brief Description of ROW20 Directivity Model (browshandel@CalQuake.com)

This presentation is a comprehensive, but brief description of ROW20 Directivity Model (hereafter, the model), which is a revised version of ROW13 model, as was presented in PEER Directivity Working Group report (PEER, 2013). The presentation addresses various features of the model and some model results for a range of applications. Topics covered are methodology and data, centering, narrow-band, period-dependency, directionality, sigma-effects, test case results, model predictions for various individual faults and systems of faults, and model heterogeneity capabilities. The model has been fully implemented in a PSHA code.

Model results for several faults of various levels of complexity in the NGA-West2 and UCERF3 databases are presented to explore and illustrate some source-rupture-and-slip-induced characteristics of near-source ground motions. These results are in the forms of site-specific effects and regional distributions of directivity for single-event-single-segment, single-event-multi-segment, and multi-event-multi-segment cases, for single hypocenter and uniformly distributed hypocenters.

Geometric complexities of UCERF3 fault system could cause multiple seismic events of different mechanisms, by rupturing across a range of discontinuities (e.g., step-overs, slip-gaps, bends, etc.), potentially producing strong and complicated near-source effects. Use of existing directivity models for complex faults necessitates significant simplifications for their implementations (by hazard code developers) and calls for assumptions in carrying out analyses (by hazard analysts). The impacts and implications of such simplifications need to be thoroughly studied before implementation of directivity models into EQ rupture forecast models and GMMs, and necessary guidelines and instructions for users must also be developed. Model results for a set of rupture-slip scenario, based on complex faults in UCERF3, will be presented to demonstrate how different simplifications in implementation of the model affect source-induced ground motions in regions adjacent to faults of various levels of complexity.

Using the model, impacts of source heterogeneities, e.g., asperities and non-uniform slip distributions on near-fault ground motions are investigated. The model has the capability of including the impacts of fault rupture-slip heterogeneities on near-source ground motions. To further develop this feature of the model, earthquake source data, consisting of slip distributions and asperity information, from several earthquakes have been compiled and used. It is shown that using the information on slip distribution and asperity features (i.e., direction and size of slip and size, locations, and strengths of asperities), when used in the above-referenced directivity-heterogeneity model, further improves the characterization of near-fault ground motions. Specifically, corrections for rupture and slip heterogeneity on the fault surface area results in further reduction of uncertainty in predicted near-source ground motions.

Details of various pieces of the model and its implementation and implications can be found in several publications. A compilation of published and unpublished documents, including a large number of test cases and model results, and data and software for interested researchers will be provided.

Overview of Chiou/Spudich Model (brian.chiou@dot.ca.gov)

The 2014 Chiou/Spudich directivity model is an update of the Spudich/Chiou (2008) model. This overview of the 2014 model will focus on: 1. Seismological and numerical rationales for using the direct point, instead of the closest point on rupture, in the definition of directivity-effect predictor (the direct point parameter, DPP); 2. Centering of DPP to a reference condition, off which directivity scaling is quantified; 3. Narrow-band formulation. An important difference between the 2014 and the 2008 model is the inclusion of the along-strike component of rupture propagation in DPP (the 2014 predictor). Using simulated ground motions from the NGA-West2 project, we illustrate the contribution to directivity effects from the along-strike rupture propagation of a RV (and NM) earthquake. The decision to incorporate or not the along-strike propagation of a RV earthquake affects the predicted directivity effect, both the amplitude and its spatial pattern around the rupture. Such decision is one of the reasons for the larger model-to-model difference in predicted directivity factors for RV earthquakes, compared to that for strike-slip earthquakes (Spudich et al., 2014). Predictor centering turns out to be a major obstacle in implementing Chiou/Spudich model in a PSHA. We propose several potential ways of reducing the computational burden in a PSHA.

A model for predicting response spectra while considering near-fault pulse-like motions (bakerjw@stanford.edu)

Jack Baker will give an overview of the directivity model and hazard analysis approach presented in: Shahi, S., and Baker, J. W. (2011). “An empirically calibrated framework for including the effects of near-fault directivity in probabilistic seismic hazard analysis.” Bulletin of the Seismological Society of America, 101(2), 742-755.

Overview of the Dabaghi and Der Kiureghian Stochastic Near-Fault Ground Motion Model (md81@aub.edu.lb)

In this talk, I will give an overview of the Dabaghi and Der Kiureghian (2017, 2018) site-based stochastic model of near-fault ground motions. To represent directivity effects, the model accounts for both pulse-like and non-pulse-like motions. The model was fitted to recorded motions in the PEER NGA West2 database, and empirical predictive relations were developed for the model parameters. The model can be used to simulate near-fault ground motion time series for specified input earthquake source and site characteristics (namely, type of faulting, earthquake magnitude, depth to the top of the rupture plane, source-to-site distance, site characteristics, and directivity parameters). A recent extension of the model and some example applications will also be mentioned.

Day 1: Directivity Model Implementations

Overview of the Watson Model: Median and Aleatory Description (JWatsonLamprey@slategeotech.com)

We expect there to be locations around a rupture that experience both positive and negative directivity effects more than others. The concept was to develop a simple model of additional mean and standard deviation to add to existing published ground motion prediction equations to account for this. The directivity effect predicted by Chiou and Youngs [2014] using the directivity parameter DPP [Spudich et al. 2013] was selected as the basis for the model. A suite of rupture geometries for strike-slip and reverse ruptures was generated and the mean and standard deviation of the change in the 5% damped pseudo-spectral acceleration at sites out to rupture distances of 70 km was calculated. Models are presented for the change in mean and standard deviation for both strike-slip and reverse ruptures that use only simple parameters as inputs.

Implementation of Directivity Models in Seismic Hazard Analysis with the UCERF3 Source Model (linda.alatik@gmail.com)

The Uniform California Earthquake Rupture Forecast Version 3 (UCERF3) seismic source model was implemented in HAZ45 to conduct probabilistic seismic hazard analysis (PSHA) in the state of California. Near-field rupture directivity effects on ground motion were incorporated in Haz45 and applied to the UCERF3 fault ruptures. The complexity of the UCERF3 ruptures required special treatment of the ruptures for directivity calculations. As a result, UCERF3 fault sources were grouped in three categories: multi-fault ruptures, smoothed multi-segment ruptures, and multi-segment ruptures. Parameters of these three types of ruptures were computed for use in Haz45. In parallel, the current generation of directivity models were evaluated focusing in capturing the epistemic uncertainty in these models. As a result, three directivity models were implemented in Haz45: Chiou and Spudich (2013), Bayless and Somerville (2013), and Bayless et al. (2020). These models are currently used to with the NGA-West2 GMPEs to calculate the hazard in a large grid of sites in California. Directivity adjustment maps will be generated as a product of this study.

Day 2: PSHA Directivity Implementation

Recap of Day 1 and Implementation Issues

Withers will provide a summary of the topics and important points from discussion covered in the previous' day session, as well as provide an overview of the schedule for this second day of the workshop.

Strategies for modeling ground motion directivity in seismic hazard analyses (jstewart@seas.ucla.edu)

A PEER project conducted from 2015-19 reviewed five models for modifying the natural log mean and within-event standard deviation of ground motion models (GMMs) to account for directivity effects in the near-fault environment. We found broad consistency for strike-slip ruptures, with positive and negative directivity effects for cases of rupture towards and away from a site of interest, respectively. We found substantial divergence among directivity models for reverse slip, with some providing maximum directivity for sites positioned to experience the peak alignment of rupture direction with fault slip direction (this occurs in the up-dip direction), while others optimize directivity based on the amount of fault rupture towards the site (even if the azimuth of rupture propagation does not align with the fault slip direction). We found four of five NGA-West2 GMMs to be centered on a condition of null directivity, and hence suitable for use along with similarly centered directivity models. We presented two deterministic methods for adjusting ground motion hazard results for the effects of directivity, one modifying ground motions for a specified hazard level based on location-specific (relative to fault) changes in mean and standard deviation, and the second producing a directivity-compatible conditional mean spectra. We provided recommendations for incorporating directivity effects into calculations within the hazard integral by either (1) modifying the mean and standard deviation of ground motion to approximately account for the effect of variable hypocenter location; (2) integrating over a location-specific distribution of the directivity parameter, which also indirectly accounts for variable hypocenter location; or (3) integrating directly over alternate hypocenter locations.

Modelling Directivity in PSHA for the next New Zealand National Seismic Hazard Model: Initial Exploration, Results and Implementation Issues (gweather@gfz-potsdam.de)

Construction of the next generation national seismic hazard model for New Zealand is currently underway, with new developments including a UCERF 3.0-style active fault model and a scaled backbone ground motion logic tree that may integrate and adapt NGA ground motion models (for both crustal seismicity and subduction). This new model will also explore the integration of modelling directivity explicitly within the probabilistic seismic hazard analysis (PSHA) in order to assess its feasibility and the implications for seismic hazard. For this purpose, several directivity models are being integrated into the OpenQuake-engine software and preliminary calculations have been undertaken using the previous generation seismic source model (Stirling et al., 2012). In this talk I will outline the issues that have emerged when implementing selected directivity models into OpenQuake and configuring the calculations, before then showing some of the initial PSHA results and highlighting the questions these raise.

Day 2: USGS NSHM Implementation

USGS Efforts on Seismic Directivity (kwithers@usgs.gov)

Withers will provide an overview of the work performed thus far to incorporate seismic directivity into the NSHMP. This includes verification of directivity models, development of an empirical and synthetic database for further validation, as well a machine learning method to merge directivity models into a unified prediction.

USGS Working Group

The working group will present various options for directivity implementation into the NSHMP and important concepts and constraints to consider.

Day 2: Future Directions

ShakeMap Considerations (wald@usgs.gov)

This talk will give an overview of directivity-related concepts related to ShakeMap and some topics to think about going forward.

RSQSim: a rich dataset of physically-plausible, complex multifault rupture slip-time histories (kmilner@usc.edu)

The Rate-State Earthquake Simulator (RSQSim; Dieterich and Richards-Dinger, 2010) is an efficient physics-based, multi-cycle earthquake simulator. Rupture slip-time histories generated with RSQSim and carried through to deterministic ground motion simulations (with CyberShake or the BroadBand platform) are in good agreement with empirical ground motion models (Milner et al., 2021). We have already simulated long period ground motions (T>=3s) with CyberShake from 715kyr of synthetic earthquakes on the UCERF3 fault system at 10 sites in southern California, including thousands of multifault ruptures. This dataset could be useful to directivity modelers to supplement limited observations of large, multifault ruptures in nature.

CyberShake/Synthetic Ground Motions (kwithers@usgs.gov)

This short talk will provide an overview of a technique to utilize the vast amount of synthetic data to improve directivity models going forward, using the CyberShake dataset as a case study.

Rupture Directivity Issues For Mw 8-9 Subduction-Zone Earthquakes (afrankel@usgs.gov)

Observations of several Mw 8-9 subduction-zone interface earthquakes indicate that they are composed of distinct sub-events (i.e., strong motion generation areas) with high stress drops and short rise times of slip, combined with broader areas of large slip and long rise times. For these earthquakes, the sub-events that generate most of the ground shaking at frequencies of engineering interest do not coincide with areas of large slip on the rupture zone. Observations of the Mw 9.0 Tohoku and Mw 8.8 Maule earthquakes, and 3D simulations of Mw 9 Cascadia earthquakes, show that sub-events can produce directivity effects at periods shorter than those expected from the rise time and extent of areas of large slip on the rupture zone.

Directivity Effects in ShakeAlert Source Solutions and Ground Motion Forecasts (gparker@usgs.gov)

In earthquake early warning applications such as the U.S. Geological Survey ShakeAlert System, rupture directivity has the potential to affect earthquake source solutions and the accuracy of ground motion forecasts, both of which determine alerting regions. ShakeAlert uses two algorithms to determine real-time earthquake magnitude and epicentral location: the Earthquake Point-Source Integration Code (EPIC; Chung et al., 2019), and the Finite-Fault Rupture Detector (FinDer; Böse et al., 2018). Both algorithms rely on near-source ground motion records that can be affected by rupture directivity. Additionally, ShakeAlert uses median predictions from ground motions models to forecast alerting regions, with the default assumption of no directivity effects. I will provide a brief overview of the ShakeAlert System, focusing on components that could be affected by rupture directivity, and then discuss plans to investigate the degree to which directivity may affect alerting accuracy, and options for improving current algorithms.