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RECIPE FOR PREDICTING STRONG GROUND MOTION ON THE SCEC BROADBAND PLATFORM

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Abstract

The recipe for predicting strong ground motions has been used for national seismic hazard mapping as well as computation of design basis ground motions for nuclear power plants in Japan. Recently, two methods based on the recipe for crustal earthquakes were implemented on the SCEC (Southern California Earthquake Center) Broadband Platform v19.4.0. The first objective of the recipe is to provide a tool that can be flexible in representing earthquake rupture models. The second is the capability to simulate damaging rupture directivity pulses that affect the near-fault response spectra. The third is generation of calibrated characterized earthquake rupture models that are applicable to simulations employing empirical Green's functions, including realistic complexity of velocity structure and site response. The recipe for crustal earthquakes has been validated for the SCEC Broadband Platform using 3-D velocity models. They performed random realization by changing the rupture starting points, location of asperities, and rupture velocity to assess simulated ground motion variability. The Irikura Recipe Method 1 is applicable to single- and multiple-segment rupture models. The source module follows the recipe where the rupture velocity of the characterized source model is variable. 80% of S-wave velocity is set to an initial value. The wave propagation module is identical to the GP (Graves and Pitarka) method. The Irikura Recipe Method 2 is applicable to single-segment rupture model. The source module is identical to the one used in Method 1. The wave propagation is handled by the low-frequency module using the FK method, and the high-frequency wave propagation is handled by the high-frequency module using the stochastic Green's function method. Comparisons between the high-frequency wave propagation modules in Methods 1 and 2 show that they produce slightly different ground motions amplitudes. One reason is that the standard stress parameter of 5 MPa set in the high-frequency wave propagation module in Method 1, is not identical to the one adopted in Method 2 which uses the stress strop calculated by the source module of the recipe. A very similar stress parameter of 6 MPa was found in a recent study of the 2016 Kumamoto earthquake in which the stress parameter was adjusted to the regional stress. We will show the performance of both methods in simulations of broadband ground motion for crustal earthquakes using the SCEC Broadband Platform.

Keywords: strong motion; broadband ground motion simulation; characterized source model; seismic hazard

1. Introduction

The SCEC (Southern California Earthquake Center) Broadband Platform [1] is an open source platform to simulate broadband ground motions within a frequency range of 0 to 20+ Hz. In Japan, the recipe for predicting strong ground motions [2] has been used for national seismic hazard mapping. Recently, the Irikura Recipe Methods 1 and 2 that are implemented on the SCEC Broadband Platform v19.4.0. In this paper, we show the performance of the methods and discuss the differences and remaining issues.

2. Recipe for strong ground motion prediction

Broadband source modeling for predicting ground motions is a key role for seismic hazard assessment. A recipe for predicting strong ground motion [2] was proposed for crustal earthquake scenarios, where a characterized source model [3] consists of characterized asperities [4] and a surrounding background area following the empirical source scaling laws based on slip inversions using strong motions. Broadband time histories on the engineering bedrock are simulated by the hybrid technique [5]: Long-period ground motions are from a deterministic approach of numerical simulations with 3-D Green's functions, and short-period ground motions are from a semi-empirical approach of the stochastic Green's function method [6, 7, 8, 9] with 1-D site response. The recipe for crustal earthquakes has been used for national seismic hazard maps [10] as well as design basis ground motions for nuclear power plants in Japan. Also, the recipe is well validated for broadband ground motions in a frequency range of 0.05 to 10 Hz of recent Japanese crustal earthquakes [11, 12]. The effect of 3-D and 1-D velocity models to simulate ground motions is also investigated [12].

The first concept of the recipe is that anybody can reproduce the same source definitively. The second concept is easy to simulate damaging rupture directivity pulses that enhance response spectra seen in the 1992 Landers, 1994 Northridge, and 1995 Kobe earthquakes. The third concept is the characterized source calibrated by empirical Green's functions including realistic complexity of velocity structure and site response. Random realization is possible by changing the rupture starting points, location of asperities, and rupture velocity to assess simulated ground motion variability. These concepts are different from source models on the SCEC broadband platform (Fig. 1).

	SCEC Broadband Platform	Recipe
Source Model	**Heterogeneous and complex**	**Characterized source model (definitive & simpler)**
Velocity Model	Long-period: 3-D or 1-D Short-period: 1-D or scattering	Long-period: 3-D Short-period: 1-D with site response
Simulation	Hybrid method	Hybrid method & EGF method
Validation	Past earthquakes & GMPEs (5% pseudo-spectral acceleration)	Past earthquakes & GMPEs (ground motion, pulse, seismic intensity)

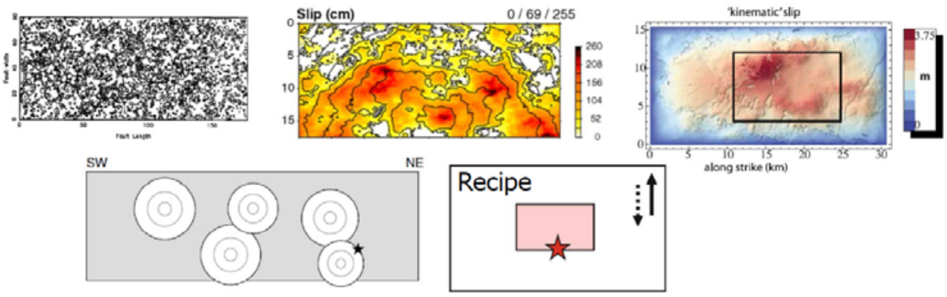

Fig. 1 – Source and ground motion characteristics for the SCEC Broadband Platform and the recipe.

In the recipe, the characterized source model for prediction of strong ground motions composes three kinds of parameters: outer, inner, and extra fault parameters. The outer fault parameters are conventional parameters characterizing the size of an earthquake, such as the rupture area and seismic moment, which give an overall picture of the source fault. The inner fault parameters define the slip heterogeneity within the seismic source. These parameters include the combined area of the asperities and the stress drop of each asperity, which have a major influence on the strong ground motions. The extra fault parameters are used to characterize the rupture nucleation and termination, such as the starting point and propagation pattern of the rupture.

3. Implementation of the recipe to the SCEC Broadband Platform

3.1 Irikura Recipe Method 1

The Irikura Recipe Method 1 [13] is applicable to single- and multiple-segment rupture models. The source module follows the recipe [2] where the rupture velocity of the characterized source model is variable. As demonstrated in [14] for the 2016 Kumamoto earthquake, 80% of S-wave velocity is set to an initial value and set by the user, although the rupture velocity Vr of the original recipe is fixed at Vr=0.72Vs, where Vs is S-wave velocity. The wave propagation module is identical to the GP (Graves and Pitarka) method [15].

The low- and high-frequency wave propagation modules of simulated ground motion are computed using the current version of the GP simulation procedure. The broadband ground motion simulation procedure is identical to the GP hybrid procedure, available on the SCEC Broadband Platform, which computes the low frequency and high frequency ranges separately and then combines the two to produce a single time history of ground motion acceleration [15]

3.2 Irikura Recipe Method 2

The Irikura Recipe Method 2 is applicable to single-segment rupture model. The source module is identical to the one used in Method 1. The wave propagation is handled by the low-frequency module using the FK method, and the high-frequency wave propagation is handled by the high-frequency module using the stochastic Green's function method.

The Irikura Recipe Methods 1 and 2 share identical methods for generating kinematic model, and for computing the low-frequency part of synthetic ground motion; the only difference is that the Irikura Recipe Method 2 computes the high-frequency part of ground motion using the stochastic Green's function method. The original codes [9] and references are at: www.j-shis.bosai.go.jp/map/JSHIS2/download.html?lang=en

The original description of the stochastic Green's function method is included in [5] The method for computing the high frequency part of ground motion, included in the Irikura Recipe Method 2, is based on [7, 10]. First, a stochastic Green's function for a small earthquake on the seismic bedrock is generated by the method of [6] following the ω-squared spectrum model and the envelope shape parameterized by [8]. The horizontal and vertical components on the seismic bedrock are computed by considering SH and SV waves, respectively, with a vertical incidence. An empirical vertical-to-horizontal spectral ratio is used to adjust the amplitude of the vertical component. Then, the stochastic Green's function on the engineering bedrock for the small earthquake is simulated by 1-D multiple reflection theory. Finally, the stochastic Green's function for a large earthquake on the engineering bedrock is summed over the fault by the semi-empirical waveform synthesis method [7] which considers variable slip on the fault. Note that the direct P-waves are not included in the computed ground motion.

3.3 Comparison

Comparisons between the high-frequency wave propagation modules in the Irikura Recipe Methods 1 and 2 show that they produce slightly different ground motions amplitudes (Table 2, Fig. 2). One reason is that the standard stress parameter of 5 MPa set in the high-frequency wave propagation module in Method 1, is not identical to the one adopted in Method 2 which uses the stress strop calculated by the source module of the recipe. A very similar stress parameter of 6 MPa was found in a recent study of the 2016 Kumamoto earthquake [14] in which the stress parameter was adjusted to the regional stress.

Table 2 – Difference between the Irikura Recipe Methods 1 and 2

	Irikura Recipe Method 1	Irikura Recipe Method 2
source module	recipe with Vr = 0.8Vs	recipe with Vr = 0.8Vs
low-frequency wave propagation module	FK method	FK method
high-frequency wave propagation module	identical to the GP method	stochastic Green's function method [6, 7, 8, 9]
stress parameter for high-frequencies	5 MPa in average	stress drop in average (e.g., 2.3 MPa)

4. Conclusions

For ground motion simulation for crustal earthquakes, the Irikura Recipe Methods 1 and 2 are implemented on the SCEC Broadband Platform v19.4.0. The source modules of both methods are identical, and the differences are the high-frequency wave propagation modules and adjusted stress parameters as input for the high-frequency wave propagation modules. Ground motion validation of both methods was performed for most Japanese crustal earthquakes including the 2000 Tottori, 2004 Chuetsu, and 2016 Kumamoto earthquakes, within a frequency range of 0.05 to 10 Hz at most stations located less than 50 km of fault distance. More simulations of broadband ground motion plan to perform for crustal earthquakes in California or other regions.

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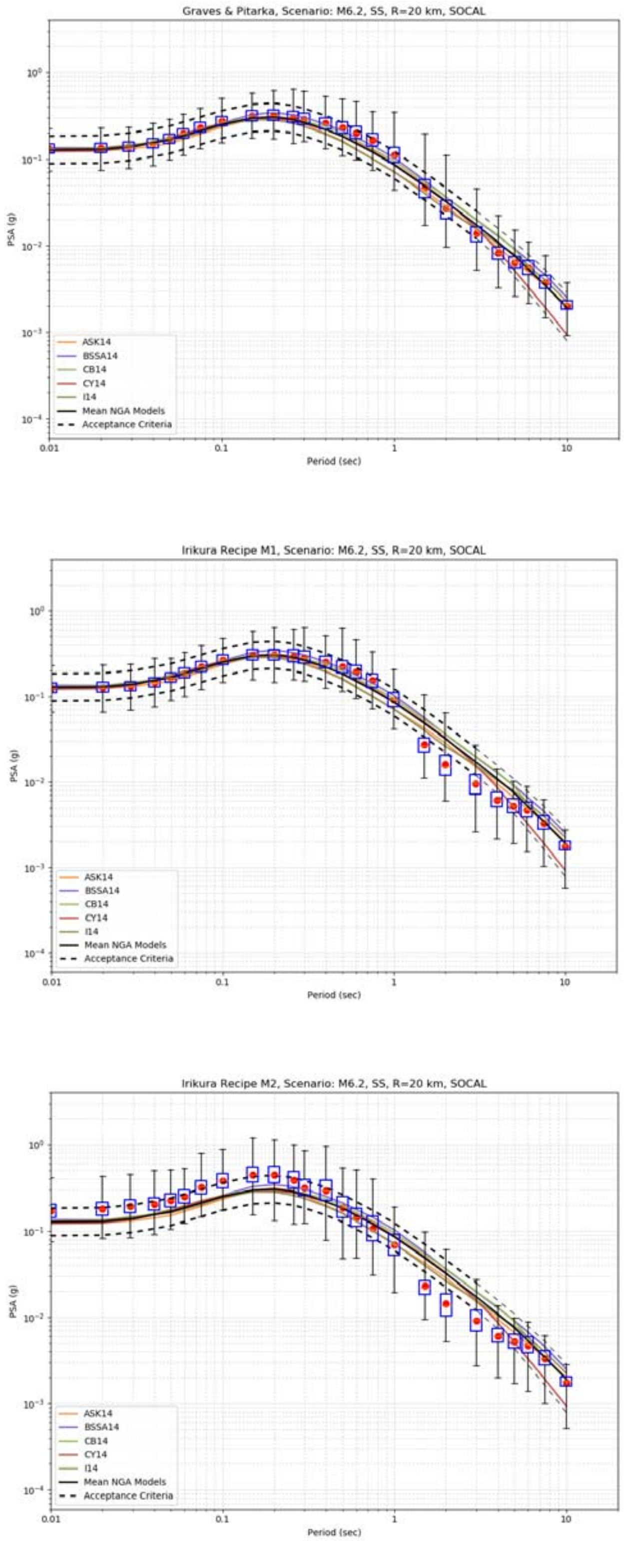

Fig. 2 – Comparison of simulated 5%-damped pseudo spectral acceleration (upper: Graves and Pitarka, middle: Irikura Recipe Method 1, and lower: Irikura Recipe Method 2) with the NGA-West2 GMPEs at fault distance of 20 km for the Mw6.2 strike-slip source scenario with 1-D velocity model of Southern California.

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