



## Research Article

# Equivalent Mechanism of EXSIM and SMSIM Under Fixed $R_{JB}$

Xueting Wang, Zhinan Xie\*

Civil Engineering, Institute of Engineering Mechanics, China Earthquake Administration, Harbin, China

## Abstract

In this study, under a fixed  $R_{JB}$  distance given by the EXSIM model, we systematically analyze the correspondence between the finite-fault model (EXSIM) and the equivalent point-source model (SMSIM) in ground motion simulations. Based on regional parameters from California, simulations are conducted for four moment magnitudes ranging from  $M_w$  6.0 to 7.5. Through the equivalent distance model and the method of minimizing spectral residuals, the SMSIM parameters that achieve the best match in response spectra between the two types of models are determined. The results show that under the same set Joyner–Boore distance ( $R_{JB}$ ), the equivalent  $R_{JB}$  value corresponding to the SMSIM simulation that best matches the EXSIM results is not necessarily equal to the  $R_{JB}$  value set in EXSIM, especially in the near field where a systematic shift is observed. More importantly, in the near-field region, to match the finite-fault effects of EXSIM using SMSIM, the equivalent depth  $h$  obtained is significantly greater than the actual set source depth. This phenomenon indicates that within the point-source framework, to equivalently represent near-field saturation effects and the influence of finite fault spatial extension, an “equivalent depth” larger than the true physical depth must be introduced as compensation. This study quantitatively reveals two key patterns: “equivalent  $R_{JB}$  shift” and “equivalent  $h$  enhancement,” establishing a parametric matching relationship from the far field to the near field. It provides important conversion criteria and physical insights for the engineering-equivalent application of finite-fault and point-source models in ground motion simulation.

## Keywords

Ground-motion Simulation, Finite-fault Model, Stochastic Point-source Model, California Region, Joyner-Boore Distance

## 1. Introduction

Ground motion simulation is a key technical approach for assessing the seismic risk of engineering structures and predicting the impact of earthquake disasters. Currently, ground motion simulation methods can be primarily categorized into three types: deterministic methods, stochastic methods, and hybrid methods. Stochastic methods, due to their effectiveness in handling the randomness of high-frequency ground motions and the complexity of seismic

sources, have been widely applied in seismic hazard analysis and engineering practice in seismically active regions worldwide. During the development of stochastic ground motion simulation methods, the stochastic point-source model (SMSIM) established by Boore (1983, 1996) laid the theoretical foundation (e.g., [1]). To better characterize finite-fault rupture processes, Beresnev and Atkinson (1998) proposed the stochastic finite-fault model FINSIM (e.g., [2]).

\*Correspondence: Zhinan Xie (wla\_2012@163.com)

Received: 7 February 2026; Accepted: 9 March 2026; Published: 31 March 2026



Copyright: © The Author(s), 2026. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

Motazedian and Atkinson (2005) further introduced the concepts of dynamic corner frequency and the percentage of active subfault area (e.g., [3]), developing the EXSIM program, which significantly enhanced the simulation capability for near-field strong motions and long-period pulses from large earthquakes. With ongoing model improvements, scholars have conducted extended research from various perspectives: Yenier and Atkinson (2014) investigated the ground motion saturation effect for moderate-to-strong earthquakes within an equivalent point-source framework (e.g., [4]); Mavroeidis and Papageorgiou (2003) proposed a mathematical model for near-fault long-period pulses (e.g., [5]); Silva et al. (1996) and Atkinson and Silva (2000) advanced the application of stochastic simulation in regional ground motion prediction through model validation and parameter calibration, respectively (e.g., [6]). Together, these studies have collectively promoted the continuous development of stochastic ground motion simulation methods in terms of theoretical refinement and engineering applicability.

SMSIM and EXSIM, as representatives of point-source and finite-fault models respectively, have had their engineering equivalence as a long-standing research focus. Previous studies have primarily concentrated on the improvement and validation of the models themselves, yet a systematic conclusion regarding the parametric correspondence between the two under specific distance conditions remains lacking. Although Boore (2009) noted that consistent treatment of key parameters could lead to comparable prediction results between EXSIM and SMSIM for smaller magnitudes or at sufficiently large distances (e.g., [7]), his study did not further quantify the specific relationship between the two models across different distances, particularly under near-field conditions.

Therefore, this study conducts a comparative analysis between EXSIM and SMSIM under the strict condition of a fixed Joyner-Boore distance ( $R_{JB}$ ) in the EXSIM model. By introducing an equivalent distance conversion model and jointly adjusting the equivalent  $R_{JB}$  and equivalent depth  $h$  in SMSIM to minimize the response spectrum residuals between the two models, this research systematically quantifies the parametric correspondence of ground motion responses between the two models from the far-field to the near-field for the first time. The study not only clarifies the applicable ranges and conversion criteria of the two models but, more importantly, quantitatively reveals two key patterns: the "equivalent  $R_{JB}$  shift" and "equivalent  $h$  enhancement." This provides direct parametric conversion guidelines for the engineering-equivalent application of finite-fault and point-source models in ground motion simulation.

## 2. A Random Simulation Model Corresponds to the EXSIM-SMSIM Methodology

### 2.1. Stochastic Simulation Methods

Accurately simulating source effects of large earthquakes

remains a central challenge in earthquake engineering. Factors such as fault geometry, slip distribution, and rupture directivity exert decisive influences on the amplitude, frequency content, and temporal characteristics of ground motions. To effectively represent these complex source features, finite-fault modeling methods have been developed and have become a key technical approach for predicting near-field ground motions during strong earthquakes.

The physical foundation of this method lies in discretizing the macroscopic fault into a series of subfault units, each treated as a point source with independent radiation characteristics. During the simulation, rupture propagates outward from the initiation point along the fault plane, sequentially triggering each subfault. The ground motion time history generated by each subfault is synthesized using a stochastic point-source approach, with the core process being the generation of random signals that conform to a specified Fourier amplitude spectrum. In practice, this involves first generating a Gaussian white noise sequence and applying a time window. The amplitude spectrum of the noise is then adjusted in the frequency domain to match a target spectrum with a Brune-type  $\omega^2$  spectral shape. Subsequently, an inverse Fourier transform is performed to obtain a physically meaningful acceleration time history for each subfault. Finally, the time histories from all subfaults are superimposed according to their respective rupture propagation times and wave propagation delays, thereby yielding the complete ground motion time history induced by the entire finite fault.

### 2.2. Simulation Parameters and Corresponding Methods

Located within the circum-Pacific seismic belt, California experiences frequent seismic activity and possesses one of the world's most comprehensive collections of ground motion records, providing a robust foundation for ground motion modeling research in the region. Yenier and Atkinson (2015) developed an equivalent point-source stochastic simulation framework applicable to California based on the NGA-West2 strong motion database, with stress parameters determined by matching the shape of observed response spectra (e.g., [8]). This model underwent systematic calibration and demonstrates strong predictive capabilities for ground motions within its validated range (magnitude M3.0–7.5, distance 1–400 km, frequency above 0.2 Hz). The simulation results show good agreement with both empirical ground motion prediction equations (GMPEs) and actual recorded data, consistently falling within a  $\pm 25\%$  error margin.

In this study, we employed both the EXSIM (finite-fault) and SMSIM (point-source) methods to simulate ground motions for earthquakes of magnitudes M6.0, M6.5, M7.0, and M7.5. The simulations utilized the California-specific path and site parameters (such as geometric attenuation, Q-model, etc.) recommended in the aforementioned literature, and ap-

plied the provided stress drop-source depth relationship to calculate stress drop. The source depths were set based on statistical characteristics of historical earthquakes in California. The stress drop formula is as follows:

$$\log \Delta \sigma = a_0 + \min[0, a_1(d-12)] \quad (1)$$

where  $d$  is the source depth (in kilometers), and  $a_0$  and  $a_1$  are model coefficients.  $a_0=2.18$ ,  $a_1=\max[0.06, 0.3-0.04M]$ .

In addition, in the EXSIM simulations, all faults were configured as vertical strike-slip faults. The fault dimensions were determined based on the target magnitude using empirical relationships from Wells & Coppersmith (1994). For each magnitude level (e.g., [9]), 50 distinct source locations were randomly selected, and 10 independent simulations were conducted at each location. The pseudo-spectral acceleration (PSA) response spectra from a total of 500 simulations were then geometrically averaged. The specific simulation parameters used are detailed in the table below:

**Table 1.** Parameters Used in the Simulation.

| Parameter                       | Value                                                                                                                                                                                                                                                                                   |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shear-wave velocity             | $\beta=3.7\text{km/s}$                                                                                                                                                                                                                                                                  |
| Density                         | $\rho=2.8\text{g/cm}^3$                                                                                                                                                                                                                                                                 |
| Quality factor                  | $Q=\max(100, 170.3f^{0.45})$                                                                                                                                                                                                                                                            |
| Site simplification (NEHRP B/C) | Table 4 of Atkinson and Boore (2006) (e.g. [10]) Frequency-amplification pairs delimited by semicolons: 0.0001Hz-1; 0.1Hz-1.07; 0.24Hz-1.15; 0.45Hz-1.24; 0.79Hz-1.39; 1.38Hz-1.67; 1.93Hz-1.88; 2.85Hz-2.08; 4.30Hz-2.2; 6.34Hz-2.31; 12.5Hz-2.41; 21.2Hz-2.45; 33.4Hz-2.47; 82Hz-2.50 |
| Kappa factor                    | $\kappa_0=0.025\text{s}$                                                                                                                                                                                                                                                                |
| Path duration                   | Rupture distance-path duration pairs delimited by semicolons: 0km-0s; 7km-2.4s; 45km-8.4s; 125km-10.9s; 175-17.4s; 270km-34.2s. Path duration increases with distance at a rate of 0.156s/km after the last nodal point.                                                                |

**Table 2.** Parameters Used for Some EXSIM Simulations.

| Magnitude | Focal depth | Stress parameter | Fault length and width |
|-----------|-------------|------------------|------------------------|
| 6         | 7km         | 75.90bar         | 14km×7km               |
| 6.5       | 7km         | 75.90bar         | 29km×10km              |
| 7         | 7.5km       | 81.28bar         | 60km×13.5km            |
| 7.5       | 9km         | 100bar           | 120km×18km             |

To delineate the transition boundary from near-field to far-field ground motions, this study adopted the following analytical procedure:

First, based on the BSSA14 empirical attenuation relationship proposed by Boore et al. (2014) (e.g., [11]), the 5% damped pseudo-spectral acceleration (PSA) response spectra for target magnitudes (M6.0, M6.5, M7.0, M7.5) at various distances were calculated. This attenuation relationship, derived from the NGA-West2 project, reliably reflects the distance-dependent attenuation trend of ground motions in the California region. Subsequently, referring to common engineering practice thresholds for negligible ground motion effects, a PSA value of  $< 0.025\text{ g}$  was set as the intensity criterion for defining the “far-field.” Finally, by comparing the

PSA attenuation curve predicted by BSSA14 with this threshold, the distance at which PSA first falls below  $0.025\text{ g}$  for each magnitude was identified and defined as the far-field boundary for that magnitude.

After establishing the far-field boundary, an equivalent distance model was introduced into SMSIM to establish a correspondence between the EXSIM and SMSIM simulation methods. The expression for this model is as follows:

$$R = \sqrt{R_{JB}^2 + h^2} \quad (2)$$

where  $R_{JB}$  is the closest horizontal distance from the observation point to the vertical projection of the surface fault rupture

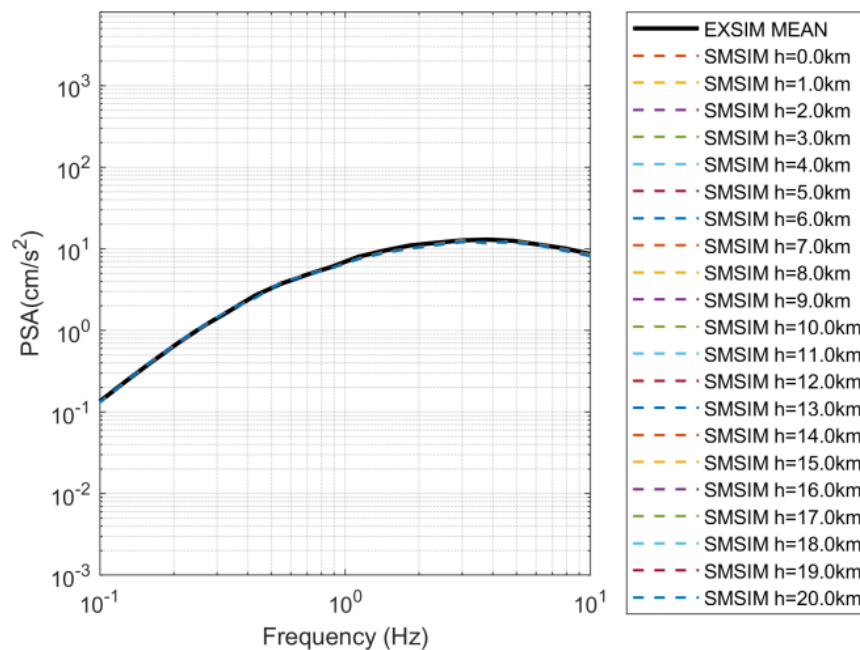
plane, and  $h$  is the equivalent depth parameter. By systematically adjusting  $R_{JB}$  and  $h$ , the response spectra simulated by SMSIM are matched to those from EXSIM. The EXSIM results used for comparison are derived from 24 stations uniformly distributed around the fault at azimuths ranging from  $0^\circ$  to  $360^\circ$ . The logarithmic average of the response spectral values across all stations at each period is taken as the representative value for that period.

### 3. Consistency Comparison Between EXSIM and SMSIM

#### 3.1. Consistency Between EXSIM and SMSIM Under Far-field Conditions

Based on the aforementioned stochastic ground motion

simulation process, this study conducted a comparative analysis of the simulation results from EXSIM and SMSIM in the far-field region for four seismic magnitude conditions:  $M_w$  6.0, 6.5, 7.0, and 7.5. The aim was to explore the engineering equivalence between the two stochastic models over long-distance ranges. By employing the BSSA empirical attenuation relationship for California to calculate the attenuation characteristics of ground motion response spectra with distance under different magnitude conditions, it can be observed that when the spectral acceleration (PSA) decays to approximately 0.025g or lower, the spectral values across different magnitudes are significantly reduced, and the spectral shapes tend to stabilize. Based on this observation, this study identifies the distance range corresponding to  $PSA < 0.025g$  as the far-field region, which serves as the starting condition for establishing an equivalent correspondence between EXSIM and SMSIM in subsequent analyses. The far-field boundaries for different magnitudes are presented in the table below:



**Figure 1.** Comparison of simulation results between EXSIM at  $R_{JB} = 130$  km and SMSIM at  $R_{JB} = 120$  km for different values of  $h$ , given  $M_w = 6.0$ .

**Table 3.** Far-field Distance Limits Corresponding to Different Magnitude Scales.

| Magnitude | Far-field limit |
|-----------|-----------------|
| 6         | 130km           |
| 6.5       | 150km           |
| 7         | 180km           |
| 7.5       | 220km           |

Under far-field conditions, statistical analysis of the EXSIM simulation results reveals that the differences in amplitude and spectral shape of ground motion response spectra obtained from observation points uniformly distributed around the fault are significantly reduced. Spectral values across different azimuthal points converge on a logarithmic scale, exhibiting consistent trends. This characteristic remains stable across all four magnitude scenarios, indicating that in the far-field region, the influence of finite fault geometry and rupture directivity on ground motions is substantially diminished. Based on this observation, this study adopts the logarithmic average of response spectra from 24 azimuthal points uniformly distributed around the fault as the representative ground motion for EXSIM simulations under a given  $R_{JB}$  condition, which is then compared with the simulation results from SMSIM.

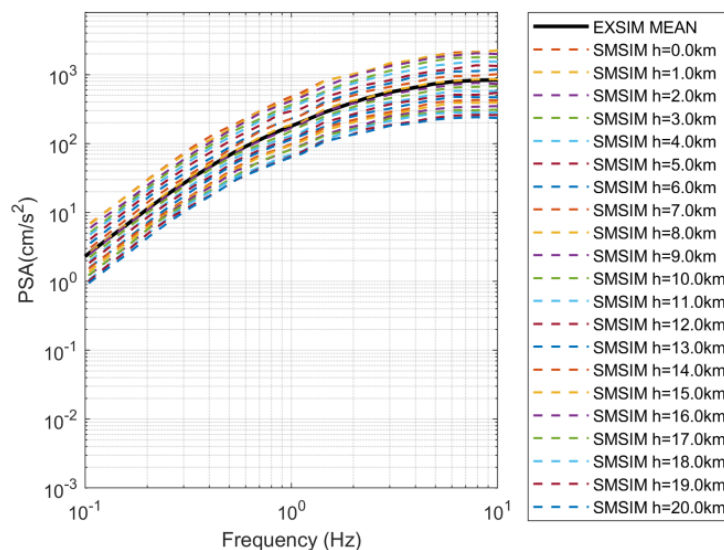
Furthermore, by comparing the representative far-field results from EXSIM with SMSIM simulations under various equivalent distances and equivalent burial depths, it can be observed that in the far-field region, the SMSIM simulation results exhibit weak sensitivity to the equivalent burial depth  $h$ . The response spectra obtained under different  $h$  values largely overlap across the entire period range. Figure 1 presents a representative example ( $M_w = 6.0$ ), where the EXSIM simulation results under the condition of  $R_{JB} = 130$  km are compared with SMSIM results under the equivalent  $R_{JB} = 120$  km condition with different  $h$  values. It can be seen that the multiple spectral

curves from SMSIM almost completely overlap throughout the entire period range and remain highly consistent with the EXSIM results. Under certain magnitude and distance conditions, the response spectra of the two models can even be nearly identical in both amplitude and spectral shape.

It should be noted that the consistency in spectral shape and amplitude between EXSIM and SMSIM simulation results under far-field conditions does not require the  $R_{JB}$  distance parameters used in the two models to be strictly equal in value. Since EXSIM explicitly describes finite-fault geometry and the radiation characteristics of subfaults, while SMSIM employs an equivalent point source to simplify the representation of the source process, the physical meanings of the distance parameters in the two models differ. Therefore, the SMSIM simulation that achieves the best match with a given EXSIM result may correspond to a different equivalent  $R_{JB}$  value, yet it can still reproduce consistent ground motion characteristics in an engineering sense. This study focuses precisely on establishing such engineering-equivalent correspondences based on the consistency of ground motion results, rather than on a one-to-one mapping of geometric distances.

In summary, under far-field conditions, EXSIM and SMSIM demonstrate stable consistency within a unified parametric framework. This provides a reliable foundation for subsequently introducing equivalent burial depth parameters from the far field to the near field and establishing a systematic correspondence between the two models.

### 3.2. The Regulatory Effect of Equivalent Burial Depth $h$ Under Near-field Conditions



**Figure 2.** Simulation results of EXSIM at  $R_{JB} = 5$  km compared with those of SMSIM at  $R_{JB} = 5$  km under different equivalent burial depths  $h$ , given  $M_w = 6.0$ .

In far-field conditions, the simulation results of EXSIM and SMSIM exhibit low sensitivity to the equivalent burial depth  $h$ , confirming the engineering equivalence of the two models

at large distances. However, as the source distance decreases and enters the near-field region, finite fault effects become significantly pronounced, and the influence of the equivalent



distance parameter in the point-source model on ground motion characteristics begins to manifest. Accordingly, this study further analyzes the regulatory role of the equivalent burial depth  $h$  in SMSIM simulations under near-field conditions.

Taking the four magnitudes  $M_w = 6.0, 6.5, 7.0$ , and  $7.5$  as examples, several typical near-field distances were selected to compare the representative ground motion results of EXSIM under the corresponding distance conditions with the simulation results of SMSIM under different equivalent burial depth  $h$  values. The results indicate that in the near-field region, the SMSIM simulation outcomes exhibit significant sensitivity to  $h$ .

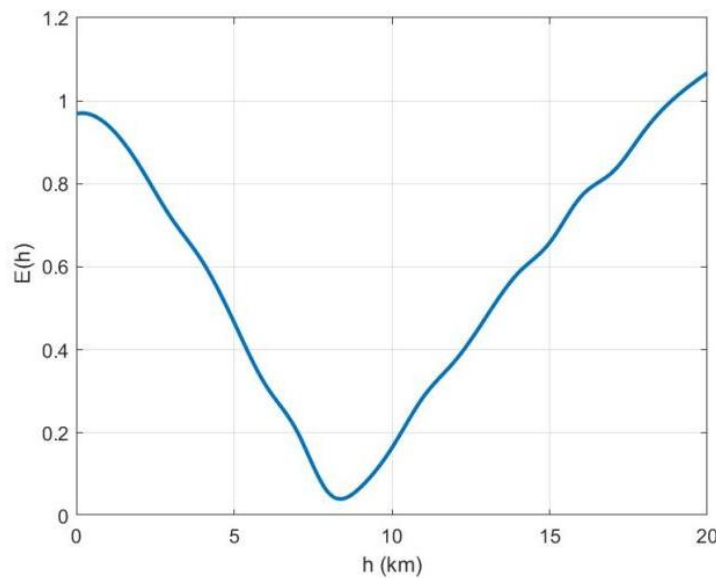
Figure 2 presents a representative example ( $M_w = 6.0, R_{JB} = 5$  km), in which the representative results from EXSIM are compared with SMSIM simulations under different equivalent burial depth  $h$  conditions. It can be clearly observed that the response spectra of SMSIM corresponding to different  $h$  values exhibit significant differences across the entire period range. Only under a specific  $h$  value do the SMSIM simulation results align well with the EXSIM results in both amplitude and spectral shape. This phenomenon indicates that under

near-field conditions, simply adopting the same geometric  $R_{JB}$  is insufficient to establish an equivalent correspondence between EXSIM and SMSIM. Introducing the equivalent burial depth  $h$  for adjustment is therefore necessary.

To quantitatively assess the consistency between the SMSIM model under various equivalent burial depth  $h$  conditions and the EXSIM simulation results, this study adopts the root mean square logarithmic residual as the evaluation criterion, defined as:

$$E(h) = \sqrt{\frac{1}{N} \sum_{i=1}^N [\ln(\text{PSA}_{\text{EXSIM}}(f_i)) - \ln(\text{PSA}_{\text{SMSIM}}(f_i; R_{JB}, h))]^2} \quad (3)$$

Where  $f_i$  is the frequency point, and  $\text{PSA}_{\text{EXSIM}}(f_i)$  and  $\text{PSA}_{\text{SMSIM}}(f_i; R_{JB}, h)$  are the ground motion response spectra at that frequency for the EXSIM and SMSIM models, respectively. By calculating the RMS logarithmic residuals for different values of  $h$  and selecting the  $h^*$  that yields the smallest residual, the optimal match between the two models under a given magnitude and distance condition can be obtained.



**Figure 3.** Relationship between residual error and equivalent burial depth  $h$  when both EXSIM and SMSIM are set at  $R_{JB} = 5$  km, given  $M_w = 6.0$ .

Figure 3 illustrates the relationship between the residual and the equivalent burial depth  $h$  calculated when both EXSIM and SMSIM adopt an  $R_{JB}$  of 5 km for  $M_w = 6.0$ . It can be observed that the residual exhibits a distinct unimodal pattern with variations in  $h$ , and The optimal burial depth  $h^*$  corresponding to the minimum residual error remains stable across different magnitude and distance conditions. This further verifies that by introducing the equivalent burial depth parameter to adjust the point-source model, the ground motion characteristics of the finite-fault model in the near-field region can be effectively reproduced.

### 3.3. Summary of Final Results

In the preceding analysis, we systematically investigated the matching performance between the EXSIM and SMSIM models across various magnitudes and distance conditions, based on the residual minimization criterion. Specifically, considering the influence of finite fault effects and source depth on ground motions, we introduced the equivalent depth parameter  $h$ . By adjusting the  $R_{JB}$  and  $h$  values in SMSIM, we progressively achieved optimal matching between the two

models in the near-field region.

To comprehensively illustrate this matching process, the following four tables present, for each magnitude condition, the  $R_{JB}$  values used in EXSIM alongside the corresponding optimal  $R_{JB}$  and equivalent depth  $h$  values for SMSIM. Through these tables, one can visually observe how the correspondence between the EXSIM and SMSIM models is optimized with variations in  $h$  across different magnitudes. This further validates that adjusting the point-source model by introducing the equivalent depth parameter can effectively reproduce the ground motion characteristics of the finite-fault model in the near-field region.

**Table 4.** For a magnitude 6.0 earthquake, the  $R_{JB}$  values used in EXSIM, the  $R_{JB}$  values of the best-matching SMSIM model, and the corresponding equivalent burial depth  $h$ .

| $R_{JB}$ (EXSIM) | Equivalent $R_{JB}$ (SMSIM) | $h^{1*}$ |
|------------------|-----------------------------|----------|
| 2km              | 2km                         | 8km      |
| 5km              | 5km                         | 8km      |
| 10km             | 10km                        | 9km      |
| 20km             | 20km                        | 7km      |
| 30km             | 30km                        | 7km      |
| 40km             | 40km                        | -        |
| 50km             | 45km                        | -        |
| 60km             | 50km                        | -        |
| 70km             | 60km                        | -        |
| 80km             | 70km                        | -        |
| 90km             | 80km                        | -        |
| 100km            | 90km                        | -        |
| 110km            | 100km                       | -        |
| 120km            | 110km                       | -        |
| 130km            | 120km                       | -        |

**Table 5.** For a magnitude 6.5 earthquake, the  $R_{JB}$  values used in EXSIM, the  $R_{JB}$  values of the best-matching SMSIM model, and the corresponding equivalent burial depth  $h$ .

| $R_{JB}$ (EXSIM) | Equivalent $R_{JB}$ (SMSIM) | $h^{1*}$ |
|------------------|-----------------------------|----------|
| 2km              | 2km                         | 9km      |
| 5km              | 5km                         | 11km     |
| 10km             | 10km                        | 13km     |
| 20km             | 20km                        | 15km     |
| 30km             | 30km                        | 15km     |

| $R_{JB}$ (EXSIM) | Equivalent $R_{JB}$ (SMSIM) | $h^{1*}$ |
|------------------|-----------------------------|----------|
| 40km             | 40km                        | 13km     |
| 50km             | 50km                        | -        |
| 60km             | 60km                        | -        |
| 70km             | 70km                        | -        |
| 80km             | 80km                        | -        |
| 90km             | 90km                        | -        |
| 100km            | 100km                       | -        |
| 110km            | 110km                       | -        |
| 120km            | 120km                       | -        |
| 130km            | 125km                       | -        |
| 140km            | 130km                       | -        |
| 150km            | 140km                       | -        |

**Table 6.** For a magnitude 7.0 earthquake, the  $R_{JB}$  values used in EXSIM, the  $R_{JB}$  values of the best-matching SMSIM model, and the corresponding equivalent burial depth  $h$ .

| $R_{JB}$ (EXSIM) | Equivalent $R_{JB}$ (SMSIM) | $h^{1*}$ |
|------------------|-----------------------------|----------|
| 2km              | 2km                         | 11km     |
| 5km              | 5km                         | 14km     |
| 10km             | 10km                        | 17km     |
| 20km             | 20km                        | 22km     |
| 30km             | 30km                        | 25km     |
| 40km             | 40km                        | 28km     |
| 50km             | 50km                        | 36km     |
| 60km             | 70km                        | -        |
| 70km             | 80km                        | -        |
| 80km             | 90km                        | -        |
| 90km             | 100km                       | -        |
| 100km            | 110km                       | -        |
| 110km            | 120km                       | -        |
| 120km            | 130km                       | -        |
| 130km            | 140km                       | -        |
| 140km            | 140km                       | -        |
| 150km            | 150km                       | -        |
| 160km            | 160km                       | -        |
| 170km            | 170km                       | -        |
| 180km            | 180km                       | -        |

**Table 7.** For a magnitude 7.5 earthquake, the  $R_{JB}$  values used in EXSIM, the  $R_{JB}$  values of the best-matching SMSIM model, and the corresponding equivalent burial depth  $h$ .

| $R_{JB}$ (EXSIM) | Equivalent $R_{JB}$ (SMSIM) | $h^*$ |
|------------------|-----------------------------|-------|
| 2km              | 2km                         | 13km  |
| 5km              | 5km                         | 18km  |
| 10km             | 10km                        | 23km  |
| 20km             | 30km                        | 19km  |
| 30km             | 40km                        | 23km  |
| 40km             | 60km                        | -     |
| 50km             | 80km                        | -     |
| 60km             | 90km                        | -     |
| 70km             | 100km                       | -     |
| 80km             | 110km                       | -     |
| 90km             | 120km                       | -     |
| 100km            | 130km                       | -     |
| 110km            | 140km                       | -     |
| 120km            | 150km                       | -     |
| 130km            | 160km                       | -     |
| 140km            | 170km                       | -     |
| 150km            | 180km                       | -     |
| 160km            | 180km                       | -     |
| 170km            | 190km                       | -     |
| 180km            | 200km                       | -     |
| 190km            | 210km                       | -     |
| 200km            | 220km                       | -     |
| 210km            | 230km                       | -     |
| 220km            | 240km                       | -     |

This study systematically reveals the compensation mechanism of equivalent parameters required for the point-source model (SMSIM) to match the finite-fault model (EXSIM). In contrast to the viewpoint of Boore (2009), even under fixed  $R_{JB}$  conditions, a significant equivalent depth enhancement effect ( $h^* > \text{actual burial depth}$ ) persists in the near field. For instance, at  $M_{6.0}$  with  $R_{JB} = 5$  km,  $h^*$  is approximately 8 km. This phenomenon essentially represents a parametric compensation by the point-source model for the near-field saturation effects of finite faults.

Compared to the equivalent point-source framework studied by Yenier and Atkinson (2014), this research finds that near-field equivalent parameters exhibit a stronger distance dependence. As the magnitude increases, the enhancement effect of equivalent depth becomes more pronounced (reaching

2–3 times the actual burial depth at  $M_{7.5}$ ), reflecting the limitations of the point-source model in representing large-scale fault ruptures. Simultaneously, the systematic shift in equivalent  $R_{JB}$  indicates that the "distance" parameter in the point-source model has evolved into an engineering parameter that comprehensively characterizes the spatial effects of finite faults.

## 4. Conclusions

This study systematically conducted a comparative analysis between the finite-fault model (EXSIM) and the equivalent point-source model (SMSIM) under fixed  $R_{JB}$  distance conditions in the EXSIM model, establishing a quantitative correspondence between the two in ground motion simulation. Based on the parameter framework for the California region and through systematic simulations of four magnitude levels from  $M_w$  6.0 to 7.5, along with spectral residual optimization analysis, the following key conclusions were derived:

1. A systematic shift in equivalent  $R_{JB}$  exists. Under the same specified  $R_{JB}$  condition, the equivalent  $R_{JB}$  value corresponding to the SMSIM simulation that best matches the EXSIM results is not necessarily equal to the original  $R_{JB}$  value set in EXSIM. This deviation is particularly pronounced and exhibits a regular pattern in the near-field region. This indicates that, in an engineering-equivalent sense, the "equivalent distance" in the point-source model is not simply equal to the geometric distance in the finite-fault model. Rather, it represents a recalibration that incorporates the influence of finite fault spatial effects on ground motions.

2. A distinct "enhancement" feature is observed in the equivalent depth  $h$ . In the near-field region, to match the EXSIM simulation results, the required equivalent depth  $h$  values in SMSIM are significantly greater than the actual source burial depths used. This phenomenon indicates that within the point-source framework, to equivalently represent the near-field saturation effects and the influence of rupture spatial extent caused by finite faults, it is necessary to introduce an "equivalent burial depth" parameter larger than the actual physical depth. This compensates for the inherent limitations of the point-source model in simulating near-field amplitude attenuation.

3. A parametric matching relationship from far-field to near-field has been established. The study quantitatively reveals the variation patterns of "equivalent  $R_{JB}$  shift" and "equivalent  $h$  enhancement" with distance, and provides datasets of optimal matching parameters ( $R_{JB}$ ,  $h$ ) for SMSIM under different magnitude and distance conditions. This outcome offers clear conversion criteria for flexibly selecting or transitioning between ground motion simulation methods based on target  $R_{JB}$  in practical engineering applications.

This study, through a quantitative analysis of the parametric correspondence between EXSIM and SMSIM under identical  $R_{JB}$  settings, not only clarifies the inherent differences in physical mechanisms and engineering representations between the



two types of models but also provides significant theoretical support and practical tools for the collaborative application of finite-fault and point-source models in ground motion simulation. The established parametric conversion framework can serve as a foundation for further developing regionalized and unified ground motion prediction methods.

## Abbreviations

$R_{JB}$  Joyner–Boore Distance

## Author Contributions

**Xueting Wang:** Conceptualization, Methodology, Writing – original draft, Data curation, Formal Analysis

**Zhinan Xie:** Resources, Software, Validation, Investigation, Writing – review & editing, Project administration, Supervision

## Funding

This work is supported by the Key Research and Development Program of Xinjiang Production and Construction Corps (No. 2024AB077).

## Data Availability Statement

The data that support the findings of this study can be found at: [http://m.w.daveboore.com/pubs\\_online.html](http://m.w.daveboore.com/pubs_online.html)

## Conflicts of Interest

The authors declare no conflicts of interest.

## References

- [1] Boore, D. M. Stochastic Simulation of High-Frequency Ground Motions Based on Seismological Models of the Radiated Spectra. *Bulletin of the Seismological Society of America*. 1983, 73(6), 1865-1894. <https://doi.org/10.1785/BSSA073006A1865>
- [2] Boore, D. M. SMSIM: Fortran Programs for Simulating Ground Motions from Earthquakes: Version 2.0—A Revision of OFR 96-80-A. U.S. Geological Survey Open-File Report 96-80-A; 1996. <https://doi.org/10.3133/ofr00509>
- [3] Beresnev, I. A., Atkinson, G. M. FINSIM: A FORTRAN Program for Simulating Stochastic Acceleration Time Histories from Finite Faults. *Seismological Research Letters*. 1998, 69(1), 27-32. <https://doi.org/10.1785/gssrl.69.1.27>
- [4] Motazedian, D., Atkinson, G. M. Stochastic Finite-Fault Modeling Based on a Dynamic Corner Frequency. *Bulletin of the Seismological Society of America*. 2005, 95(3), 995-1010. <https://doi.org/10.1785/0120030207>
- [5] Mavroeidis, G. P., Papageorgiou, A. S. A Mathematical Representation of Near-Fault Ground Motions. *Bulletin of the Seismological Society of America*. 2003, 93(3), 1099-1131. <https://doi.org/10.1785/0120020100>
- [6] Silva, W. J., Gregor, N., Darragh, R. B. Engineering Ground Motion Hazard Analysis. *Proceedings of the International Workshop on Site Response Subjected to Strong Earthquake Motions*. 1996, 2, 61-86.
- [7] Atkinson, G. M., Silva, W. J. Stochastic Modeling of California Ground Motions. *Bulletin of the Seismological Society of America*. 2000, 90(2), 255-274. <https://doi.org/10.1785/0119990067>
- [8] Boore, D. M. Comparing Stochastic Point-Source and Finite-Source Ground-Motion Simulations: SMSIM and EXSIM. *Bulletin of the Seismological Society of America*. 2009, 99(6), 3202-3216. <https://doi.org/10.1785/0120090056>
- [9] Yenier, E., Atkinson, G. M. Regionally Adjustable Generic Ground-Motion Prediction Equation Based on Equivalent Point-Source Simulations: Application to Central and Eastern North America. *Bulletin of the Seismological Society of America*. 2015, 105(4), 1989-2009. <https://doi.org/10.1785/0120140332>
- [10] Wells, D. L., Coppersmith, K. J. New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. *Bulletin of the Seismological Society of America*. 1994, 84(4), 974-1002. <https://doi.org/10.1785/BSSA0840040974>
- [11] Atkinson, G. M., Boore, D. M. Earthquake Ground-Motion Prediction Equations for Eastern North America. *Bulletin of the Seismological Society of America*. 2006, 96(6), 2181-2205. <https://doi.org/10.1785/0120050245>