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STOCHASTIC SIMULATION OF STRONG GROUND MOTIONS FOR WESTERN HIMALAYA REGION

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Abstract

Stochastic simulation of strong ground motion is commonly based on Brune's far-field spectrum with point source assumption. The effect of finite fault rupture is considered either by discretizing the large rupture area into smaller subfaults, with each subfault assumed to be a stochastic point source, or by using an equivalent source to site distance. Thus near field effects are not accounted in the currently used stochastic simulation via seismological source model approach. This paper proposes to use weighted combination of Brune's near field and far-field source spectra in the stochastic simulation method. The application of the proposed simulation method to Mw 6.8 Uttarkashi earthquake of October 20th,1991 and Mw 6.5 Chamoli earthquake of March 28th,1999 in Western Himalayan Region has shown considerably improved results compared to the commonly used point source far field approximation.

Keywords: Stochastic simulation; Brune's source spectra; near-field; far-field

1. Introduction

Availability of strong motion records is an essential requirement to define seismic loads for the purpose of earthquake resistant design, retrofitting of structures and to develop empirical ground motion prediction equations. Region specific empirical ground motion prediction equations are commonly used for estimation of seismic hazard and microzonation studies. But strong motion database in a region is generally not distributed uniformly over the distance (0-300) and magnitude (4-8) ranges of engineering interest. To fulfill this gap, synthetic data generation by simulations based on regional seismic parameters can be used as an alternative of recorded earthquake waveforms [1]. The success of all the simulation techniques mainly depends on the type of mathematical function used to physically model source mechanism and the input parameters used to define this function. Regional wave propagation and site effects also influence the ground motion significantly. On the basis of the frequency content in strong ground motion records, simulation technique is divided into two main categories, viz.: deterministic and stochastic. Deterministic simulation technique is used to synthesize strong ground motion having frequencies less than one hertz. This approach is based on the numerical solution of wave equation and requires a precise definition of source and velocity model for the region of interest [2]. On the other hand, stochastic technique is used to simulate high frequency ground motion (f>1Hz) by modeling it as white noise. This method is generally capable of matching the spectral amplitudes of the average horizontal component of far-field S-waves, but is generally not capable of matching the recorded waveforms [3]. This method has been widely used in many tectonic active regions of the world due to very few input parameters required compared to the other simulation techniques. In the present study, we extend the use of stochastic simulation method to include the combined effect of near- and far-field, which in its commonly used form is suitable for far-field simulations only.

A number of improvements have been introduced in stochastic point simulation technique since its introduction by Boore in 1983 [4]. Important among these are inclusion of effective distance in point source simulation and the use of dynamic corner frequency with pulsing of subfaults in finite source simulation. However, all these still use far- field site spectrum, obtained by multiplication of Brune's far-field source model with path and site effects. In case of finite source simulation, fault rupture plane is divided into smaller subfaults and each subfault is treated as Brune's far-field point source. The final time series at a site is obtained by adding times series for all the subfaults with proper time delay. The success of both stochastic point source simulation and finite source simulation mainly depends on the accurate specification of Fourier acceleration amplitude spectra, which in reality has both far- field and near-field contributions in proportion to the source-to-site distance relative to the fault rupture dimension. The current practice of using only far-field spectrum in stochastic simulation technique is unable to provide accurate and realistic ground motion in spite of the various improvements mentioned before.

To have physically realistic stochastic simulation of ground motion, this study emphasizes on the shape of the source spectrum in stochastic method. Use of a modified shape of Fourier amplitude spectrum has been proposed that takes into account both the far- and near-field effects. To incorporate this modification, Fourier acceleration site spectrum is defined as weighted combination of the Brune's far-field and near-field source spectra. Following the idea from Trifunac [5], the weights are so defined that at as the distance increases from zero to four times the rupture dimension, the contribution of near-field spectrum decreases from 100% to only 5%. The use of the weighted spectrum shape in stochastic simulation is illustrated for two moderate magnitude earthquakes in the Western Himalaya, for which several strong motion records are available. These earthquakes are Mw6.8 Uttarkashi earthquake of 20 october 1991 and Mw6.5 Chamoli earthquake of 29 march 1999. The numerical results on 5% damped PSA spectra obtained using the present method are seen to match closely with the corresponding spectra of recorded accelerograms as compared to those based on only the far-field approximation in vogue.

2. Methodology

The stochastic simulation methodology is commonly used by defining the Fourier amplitude spectrum of ground motion at a site from Brune's far-field source spectrum. For this purpose, the shear wave acceleration spectrum in far-field at distance R from a source with magnitude Mw is expressed as multiplication of source, path and site effects in frequency domain as [3].

$$A_{FF}(f)=\frac{R_{\theta\varphi}*FS*PRT*M_0}{4\pi\rho\beta^3}*\frac{(2\pi f)^2}{1+\left[\frac{f}{f_c}\right]^2}*\mathrm{G(R)}*\exp\left(-\frac{\pi fR}{Q(f)R}\right)*\exp(-\pi kf)*SI(f) \tag{1}$$

In this equation, PRT is a partition factor, FS is free surface amplification factor, M_0 is seismic moment in dyne-cm, β is shear wave velocity in km/sec, and ρ is density of crust. Further, fc is the corner frequency defining the shape of Brune's far-field source spectrum, G(R) represents the geometrical attenuation, term exp (- πfR/(Q(f)β)) represents the anelastic attenuation with Q(f) as frequency dependent quality factor, term exp(-πkf) accounts for fast decay of high-frequency ground motion amplitudes observed in recorded data, and SI(f) accounts for the site amplification effects.

The finite fault rupture effects with the use of site spectrum of far-field in simulation can be accommodated by representing the rupture plane by a number of Brune's subfaults [6], but this is not really able to generate the near field effects. The present study therefore proposes to use Brune's near field source model in combination with the far-field model. Analogous to the expression of eqn. (1), by applying free surface amplification factor, partitioning of energy into two horizontal components, site amplification factor, and anelastic attenuation factor to Brune's near field source spectrum, the near-field shear wave site acceleration spectrum can be mathematically expressed as follows

$$A_{NF}(f)=\left[\frac{\sigma*\beta*FS*PRT}{\mu}\right]*\left[\frac{2\pi f}{\sqrt{(2\pi f)^{(2)}+(\tau)^{(-2)}}}\right]*\left[\exp\left(-\frac{\pi fR}{Q(f)R}\right)*\exp(-\pi kf)*SI(f)\right] \tag{2}$$

Where σ is stress drop in bars, μ is the modulus of rigidity in dyne/cm^2, β is the shear wave velocity in km/sec, and τ is a characteristic time of the order of the dimension of the fault divided by shear wave velocity. The associated corner frequency f_τ in near field source spectrum is equal to (1/τ). In case of a circular crack model with radius *r*, $\tau=1/f_\tau=r/\beta$ [7].

As the ground motion at a site is expected to be influenced by near field effects up to considerable distance from the source, it is proposed to define the site spectrum for stochastic simulation as a suitable combination of the far-field and near field spectra. This combination can be affected as the weighted sum with the weights taken from Trifunac [5], who used combination of near-field and far-field spectra for extrapolation of empirical scaling equation of Fourier amplitude spectra below 0.1 Hz. Thus, following Trifunac [5], the final shape of the deterministic site amplitude spectrum at distance R from the source can be estimated by a weighted combination of far-field site spectrum given in equation (1) and near-field site spectrum given in equation (2) as

$$AW(f)=e^{-\left(\frac{3R}{4S}\right)}*A_{NF}(f)+\left(1-e^{-\left(\frac{3R}{4S}\right)}\right)*A_{FF}(f) \tag{3}$$

Here, S is the characteristics rupture dimension, taken as radius of a circular rupture plane and R is distance from source to site, taken as the effective distance defined in Boore [9].

Having defined the site spectrum as weighted sum of far-field and near-field spectra, the stochastic simulation is carried out exactly in the same manner as done using only far-field spectrum defined by eqn. (1). To investigate the effect of the proposed modification on the site spectrum of stochastic simulation, example results are computed at different distances using source, path, and site parameters of Chamoli earthquake given in Table-3. The weighted site spectra, along with far-field and near-field components, are plotted in Fig. 1 for four different distances. It is seen that the weighted site spectra are quite different at closer distances, and it converges to the far-field spectrum as the distance increases to very large values. Also, the rate of fall of amplitude below the corner frequency in weighted spectrum is slower as compared to the far- field spectrum. This effect is not possible to be generated in a realistic way by ad hoc measures commonly adopted in stochastic simulation with the far-field spectrum.

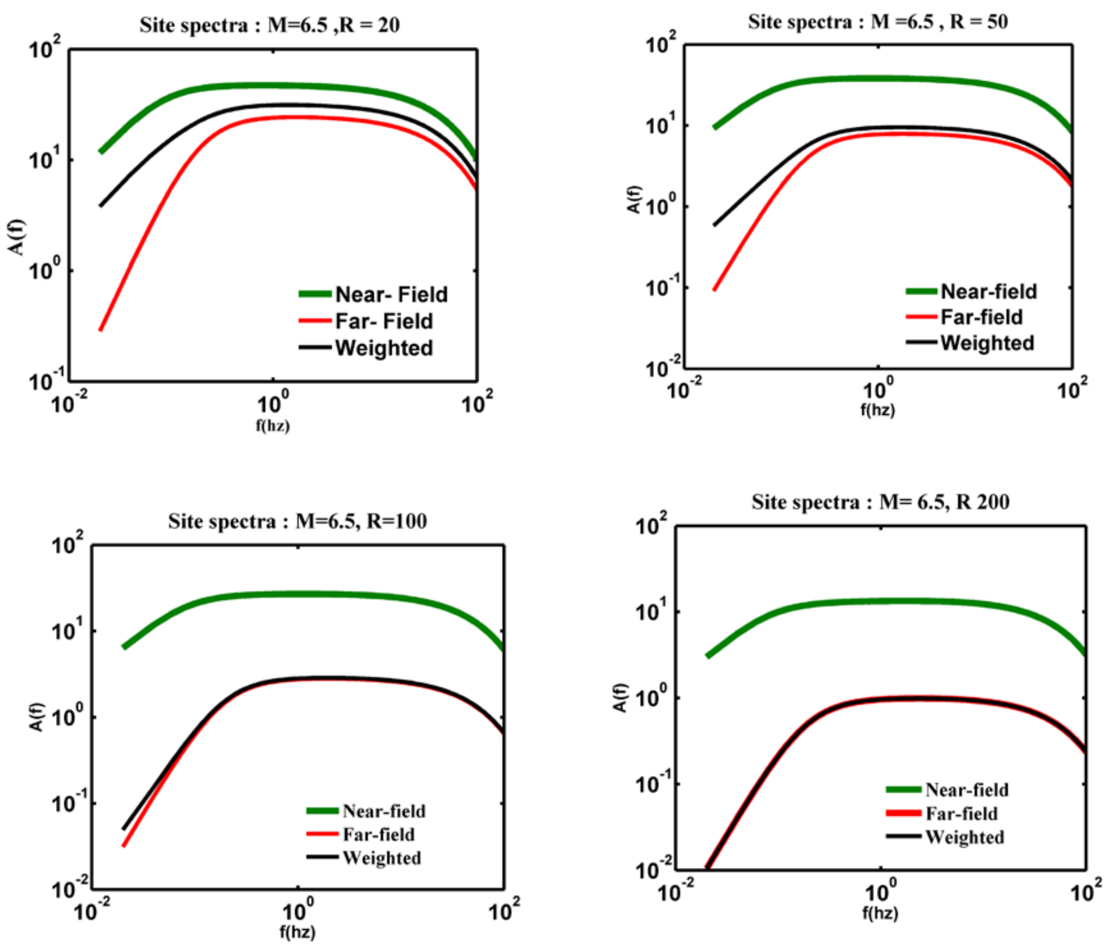

Fig. 1 - Comparison among far-field, near-field and weighted combination based site acceleration spectra for M=6.5 and R=20, 50, 100, and 200 km.

3. Results on Ground Motion Simulation

To illustrate the use of weighted site spectrum in ground motion simulation, numerical results are computed for two important earthquake events, viz. Uttarkashi and Chamoli earthquakes, in Western Himalaya. These earthquakes provided twenty eight and thirteen strong motion records respectively in Garhwal and Kumaon regions of Himalaya. All these data are recorded in analog form and has been converted into digital form by Chandrasekaran and Das [8] with sampling period of 0.02s. To apply instrument and baseline corrections, the data are band-pass filtered with variable lower frequency between 0.25 and 1.1 Hz and upper frequency between 22 and 25 Hz. Thus the observed records are lacking in low frequency contents. The Fault Plane solution of both these earthquakes has been taken from Centroid Moment Tensor Solutions by Harvard University. To illustrate that how the proposed combination of near–field and far-field spectra is able to provide more realistic stochastic simulation, numerical results are computed with the corresponding recorded data for four selected strong ground motion records of Uttarkashi earthquake and two selected records of Chamoli earthquake to cover both near- and far-field cases. Details of these records are given in Tables 2 and 3. By comparing the stochastic point source simulation by SMSIM with Finite Fault simulation by EXSIM, Boore [9] proposed the use of effective distance in SMSIM to get the results compatible with EXSIM. Estimates of this equivalent distance are also given in the last column of Tables-1 and 2, which has been used in the present simulation.

Table 1 - Details of selected strong motion records for Uttarkashi earthquake

Station Name	**Station Latitude**	**Station Longitude**	**Epicentral distance(km)**	**Hypocentral Distance(km)**	**Effective Distance(km)**
Almora	29.58	79.65	152.95	154.12	155.98
Bhatwari	30.80	78.60	19.35	27.12	25.61
Tehri	30.37	78.50	49.61	53.12	55.74
Uttarakhashi	30.73	78.45	32.51	37.66	36.64

Table 2 - Details of selected strong motion records for Chamoli earthquake

Station Name	**Station Latitude**	**Station Longitude**	**Epicentral distance(km)**	**Hypocentral Distance(km)**	**Effective Distance(km)**
Gopeshwer	30.40	79.33	8.7	23	22.75
Chinyalisaur	30.55	78.33	105.68	107.75	106.46

The various earthquake input parameters required for stochastic simulation have been adopted from Harbindu et al. [10] as given in Table-3. Also, the path parameters given by them have been adopted according to which quality factor is $140f^{(1.018)}$ and Geometrical attenuation is 1/R up to distance 100 km and $1/\sqrt{(100R)}$ beyond 100 km.

Table 3 - Summary of various modeling parameters used for the stochastic simulation of Uttarkashi and Chamoli earthquakes

Input Parameter	**Earthquake**	
	Uttarkashi	**Chamoli**
Location	30.74N 78.79E	30.41N 79.42E
Strike , Dip	317, 14	280,7
Focal depth	19	21
Magnitude	6.8	6.5
Stress drop	33	105

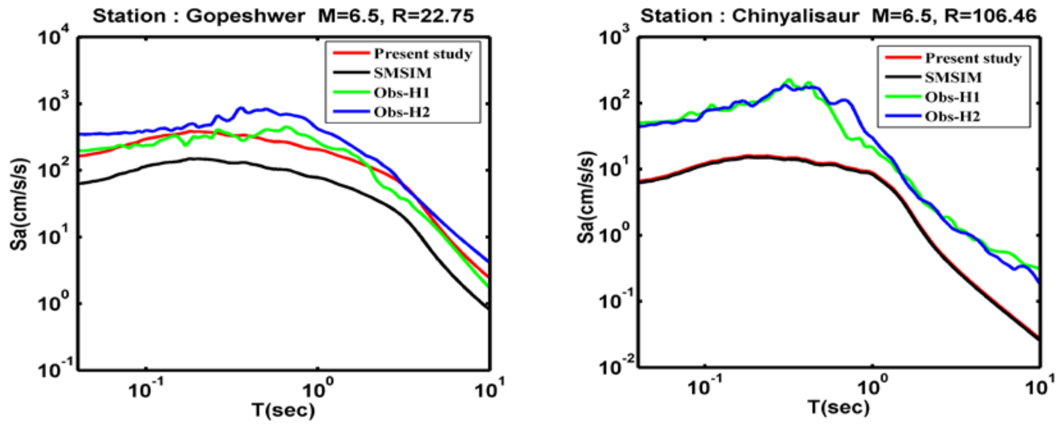

Fig. 2 (a) - Comparison of weighted simulated 5% damped acceleration response spectra with far-field acceleration response spectra and observed response spectra of two horizontal component of records for Chamoli earthquake at stations Gopeshwer and Chinyalisaur

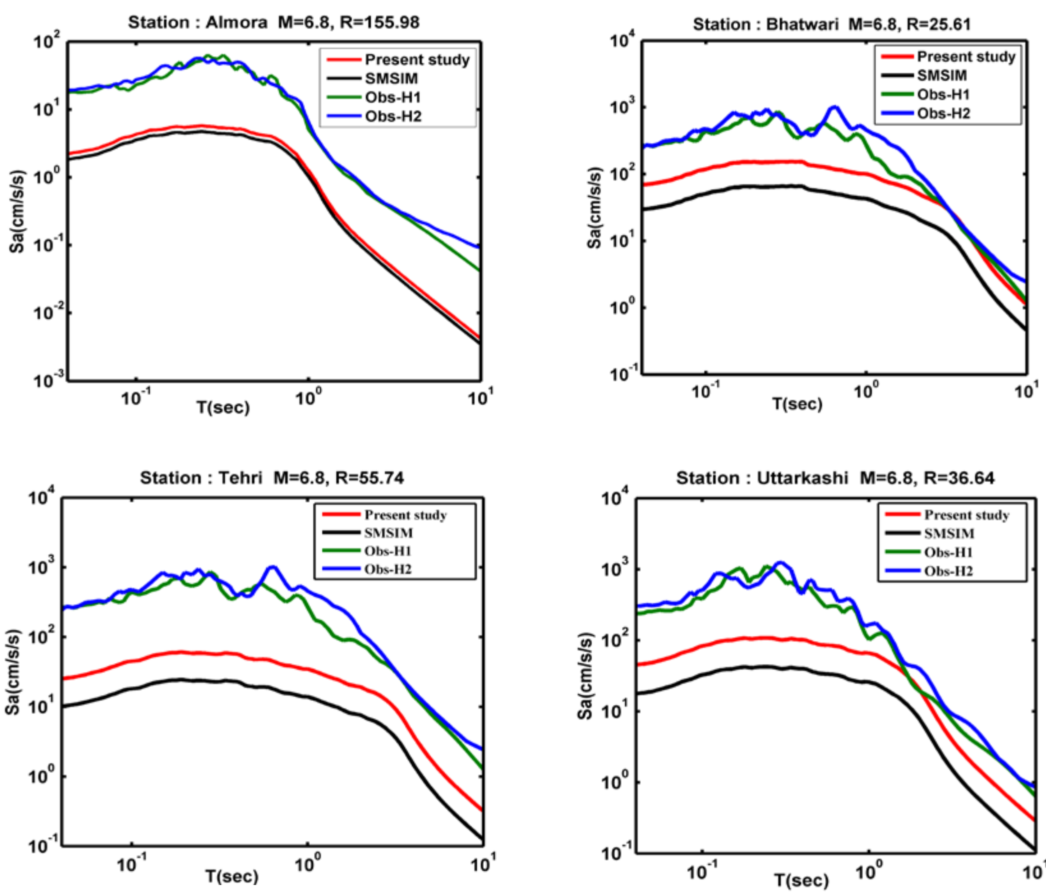

Fig. 2(b) - Comparison of weighted simulated 5% damped acceleration response spectra with far-field acceleration response spectra and observed acceleration response spectra of two horizontal components of records for Uttarkashi earthquake at station Almora, Bhatwari, Tehri and Uttarkashi

Fig 2(a) and (b) shows the comparison of the PSA spectra of two horizontal components of the selected records of the Uttarkashi and Chamoli earthquakes with the spectra of simulated accelerograms based on the proposed weighted site spectra as well as based only on the far-field spectra. It is seen that in the near field (e.g. results for Gopeshwar site in case Chamoli earthquake and at Bhatwari site in case of Uttarkashi earthquake) the use of weighted site spectra is able to provide more realistic results with closer matching with the spectra of recorded accelerograms. The near field effects are seen to play an important role up to quite large distances (e.g., Uttarkashi and Tehri sites for the Uttarkashi earthquake), establishing the usefulness of the weighted site spectrum. The slight underestimation of the results in certain cases may be attributed to the site amplification effects, which are not considered in the present simulation. The amount of amplification at a site depends on the many factors including geology, layer thickness and shear wave velocity gradient [11]. As all the strong ground motion stations are installed in higher Himalaya terrain and in the meta-sedimentary lesser Himalaya, the amplification due to thick sedimentary cover at all stations is expected to be very low. However, weathered rock, fractured rock and loose sediments of the river valley below the station may cause amplification of ground motion, which when accounted, will improve the present results further.

4. Discussion and Conclusion

Use of a weighted far-field and near-field site spectrum has been proposed in stochastic simulation in place of commonly used far-field acceleration site spectrum based on single corner frequency source model. Illustrative numerical results obtained using the weighted spectrum for two damaging earthquakes in northwest Himalaya have shown much better matching with recorded strong motion data at several sites in near and intermediate field regions compared to the use of only far-field spectrum. The use of even finite fault rupture in stochastic simulation with only far-field site spectrum is unable to manifest the near-field effects seen in the present results. It may thus be concluded that the current practice of using only the far-field point source site spectrum needs to be replaced by the weighted site spectrum of both near- and far-field site spectra. The concept of weighted site spectrum has been implemented in this paper for the idealized case of circular rupture with Brune's source spectra, which would be extended in future studies to rectangular faults with more realistic source spectra and weighting factors.

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