

Stochastic Finite Faulted Ground-Motion Simulation Incorporating Slip Effect and Time Duration

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Abstract: The 26 January 2001 Bhuj earthquake (Mw 7.6) produced near-source peak ground accelerations (PGA) of 0.31–0.37g [1], but the mainshock was recorded only at Ahmedabad, 237 km away. An in-house stochastic finite-fault model based on dynamic corner frequency [2] incorporates heterogeneous slip and variable-density quarter-wavelength site amplification for Ahmedabad alluvium. The high-frequency decay parameter ($\kappa = 0.0237$ s) was estimated from the record and checked against an M 5.3 aftershock; the stress parameter was calibrated to observed PGA. At the actual station distance, simulated PGA agreed within 1%, and Fourier and 5%-damped response spectra showed no systematic bias. A one-dimensional transfer function calibrated to the H/V ratio reproduced basin resonance near 0.55 Hz. However, the North American path-duration model overpredicted observed 5–95% duration by about 18%, while a regional linear relation overpredicted it by approximately twofold. The amplitude model agreed with a regional model [3] within one standard deviation, supporting Kachchh spectral prediction. Duration remains unresolved from a single mainshock record. Transfer to the Himalaya requires recalibration of stress, duration and attenuation parameters; the approach was also applied to the 1999 Chamoli earthquake (Mw 6.8) [4].

Keywords: Bhuj earthquake, Stochastic finite-fault, Heterogeneous slip, Dynamic corner frequency, Site amplification, Ground-motion duration, Himalayan seismicity.

Introduction

The 26 January 2001 Bhuj earthquake (Mw 7.6) was a destructive intraplate event in the Kachchh region of India. Reported near-source PGA ranged from 0.31g to 0.37g [1], yet the mainshock was instrumentally recorded at only one station, Ahmedabad, approximately 237 km from the source. This limited observational coverage makes reconstruction of the recorded shaking important for assessing the finite-fault simulation approach. The study examines ground-motion amplitude, frequency content, basin resonance and significant duration, rather than treating agreement in PGA alone as sufficient validation.

Its central objective is to evaluate an in-house stochastic finite-fault method incorporating

heterogeneous slip and site effects, then consider its relevance to a different tectonic setting: the Himalayan collision zone. The method is also applied to the 1999 Chamoli event [4].

Methodology

Ground motions were simulated using an in-house stochastic finite-fault code adopting the dynamic-corner-frequency formulation of [2]. Heterogeneous slip was incorporated in the fault representation. To account for the soft alluvial conditions at Ahmedabad, the model used variable-density quarter-wavelength site amplification. The observed mainshock provided the basis for calibrating source and site parameters at the true station distance.

The high-frequency decay parameter was estimated as $\kappa = 0.0237$ s from the Ahmedabad record and independently checked against an M 5.3 aftershock recorded at a second station. The stress parameter was adjusted to match the observed peak ground acceleration. A one-dimensional transfer function, calibrated using the mainshock record's horizontal-to-vertical (H/V) spectral ratio, was used to represent deep-basin resonance at approximately 0.55 Hz.

Model performance was examined through PGA, Fourier amplitude spectra, 5%-damped response spectra and significant duration over the 5–95% energy interval. Duration predictions were evaluated using the North American default path-duration model and a linear regional relation. The amplitude results were also compared against the regional ground-motion model of [3].

Results and discussion

At the observed station distance, simulated PGA agreed with the recorded value to within 1%. Fourier and 5%-damped response spectra were reproduced without systematic bias. Incorporating the site transfer function also recovered the recorded deep-basin resonance near 0.55 Hz. These comparisons indicate strong amplitude and spectral performance for the calibrated Bhuj–Ahmedabad configuration.

Significant duration remained less well constrained. The North American default model overpredicted the observed 5–95% duration by approximately 18%, while a linear regional relation gave a prediction roughly twice the recorded duration. The difference between successful amplitude matching and weaker duration prediction is a principal result of the study. Because only one mainshock record was available, the appropriate path-duration relationship for this stable-continental setting remains unresolved.

The calibrated amplitude estimates also agreed with the regional ground-motion model [3] within one standard deviation, supporting use of the approach for spectral estimation and design-code comparison in Kachchh. Table 1 summarises the reported performance; it compiles the researcher's stated results rather than introducing additional model runs.

Table 1. Reported simulation performance and limitations

Measure	Reported outcome
PGA agreement	Within 1% of observed PGA
Spectral response	Fourier and 5%-damped spectra: no systematic bias
Basin response	Resonance reproduced near 0.55 Hz
5–95% duration	North American model: ~18% high; regional linear model: ~2× observed
Regional amplitude check	Within one standard deviation of [3]

Himalayan Applicability

The original study distinguishes the stable Kachchh region, associated with high stress drops, from the actively convergent Himalayan collision zone. The Himalaya has more complex crustal geometry and greater near-surface energy attenuation. Accordingly, regional stress-drop values, path-duration relations and attenuation parameters should be recalibrated rather than transferred unchanged from the Bhuj calibration. The developed modelling approach was also applied to the 1999 Chamoli Himalayan earthquake, reported as Mw 6.8 in the researcher's abstract [4]; no separate quantitative validation statistics are given for that application.

Conclusion and Recommendations

The stochastic finite-fault method reproduced Bhuj ground-motion PGA and spectral characteristics at Ahmedabad and captured basin resonance through H/V-calibrated site response. Duration estimation is the principal unresolved limitation, with both tested path-duration models overpredicting the recorded value. Further regional records would be needed to resolve that limitation. For Himalayan applications, the source, duration and attenuation parameters require region-specific calibration. This distinction between demonstrated Bhuj performance and prospective Himalayan transfer is important for interpreting the results.

References

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