Earthquake Engineering, Tenth World Conference © 1992 Balkema. Rotterdam. ISBN 90 5410 060 5

A stochastic rupture process model for synthetic S-waves accelerograms computations and associated response spectra for large faults

A. Herrero
Bureau de Recherches Géologiques et Minières, Marseille, France & Institut de Physique du Globe, Paris, France

P. Bernard
Institut de Physique du Globe, Paris, France

P. Mouroux
Bureau de Recherches Géologiques et Minières, Marseille, France

ABSTRACT: Synthetic S-waves accelerograms are computed from a kinematic stochastic rupture process defined on a fault plane. This method allow to obtain broad band velocity response spectra for station located near the source where classical statistics methods still have an important lack in data.

1 INTRODUCTION

Most methods for standard response spectra calculations are based on statistics, generally depending on magnitude/distance couple, established from an accelerograms data set (Mohammadioun and Mohammadioun (1980), Petrovski (1986), Fukushima (1990)). The problem of this approach is the important heterogeneity of natural records induced by both source and propagation path variabilities and the undersampling of the different couple configurations as well.

An alternative to this method is the use of synthetic data. For a configuration where the epicentral distance is greater than the fault characteristic size, methods have been developped, based on accelerometric spectra. These methods consists in convolving a theoretical spectra scaled by the classical seismic laws (Brune (1970)) with a white noise reproducing the stochastic behaviour of the real accelerograms in time (Boore (1983), Bernard (1987)). These methods give good results and are consistent with the tables established on observed data by the first method. It is important however to obtain reliable models near the source where the strongest seismic damages is expected to occur, especially for large seismic source. In this case, the point source approximation is not valid and we have to use a expensive seismic source.

2 MEDIUM AND FAULT MODELISATION

We first have to define a rupture process for a large earthquake. We choose a kinematic model. Only S waves radiation are taking into account for their important horizontal shear characteristics.

2.1 Parametrization

We assume that the fault is a rectangular plane. This fault plane is discretized in elementary subfaults (Yoshida (1986)). With each subfault, we associate an elementary source function D. This function is a ramp defined by its final dislocation Δu and its rise time τ. We also have to impose an history of the rupture on the fault plane. For this, we define the rupture times Tr on the nodes of our grid (Figure 1). Thus, we know the rupture time in any point of the fault plane assuming that the rupture time is linear on the border of the subfaults.

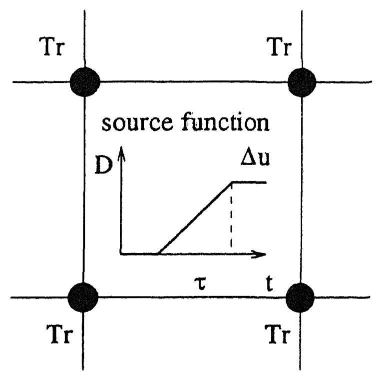

Figure 1. Elementary subfault with the associated graph of the source function.

In this first step, in order to simplify the study, we fix the rupture velocity and the rise time as being constant on the fault plane. We take a very short rise time (0.05s). That means that we work with a quasi Heaviside elementary source function.

In the same way, we take the simplest model of medium, an homogeneous isotropic full-space. To propagate in this medium our rupture process, we use the ray theory associated with the isochrone concept (Bernard and Madariaga (1984), Spudich and Frazier (1984)). This concept is a high frequency approximation where we assume that all the energy radiated by the fault plane comes from the rupture front which is time when the slip function is a Heaviside. We can now redefine the parametrization of the rupture time into isochrone time. Isochrone time is a relative value depending on the fault rupture history and a recording station. For a point on the fault plane, the *isochrone time of this point* is the rupture time plus the time taking by the wave to reach the station. As the rupture time is linear in our model, it is easy to demonstrate that the isochrone time on the fault plane is linear as well.

We want to apply this modeling for the need of the engineering seismology. Thus, we need broad-band accelerograms with frequencies up to $10Hz$. This implies, depending on the rupture velocity on the fault, a discretization of about $100m$. As we want to model large seismic source, the number of subfaults becomes quite large. We cannot manage such number of values in a true deterministic way. We have to find statistic distributions of our parameters. Now, the only free parameter of our rupture process is the final dislocation, all the others are fixed. The problem is: does a distribution of dislocation on the fault plane exists, which gives a correct spectral and temporal shape of accelerograms and what is it?

2.2 Synthetic Green function

In order to understand more the problem, if we consider the radiation in terms of acceleration of a subfault crossed by a constant velocity rupture front, we obtain at a given station the accelerogram shown in figure 2. This accelerogram is composed by four narrow box function of approximatively τ width (depending on the directivity). This signal have a spectrum in ω^2, the classical shape for real accelerogram without attenuation (Brune (1970)). We can say that it is a synthetic Green function. Indeed, the only difference with empirical Green function is the distribution of the phasis. We can pose the problem now in term of summation of Green functions. We have to pass from a unitary accelerometric spectrum $|\tilde{a}|_g$, defined by a corner frequency f_g bounded by the griding space, to the spectrum $|\tilde{a}|_f$ generated by the whole of the fault (figure 2).

In figure 2, it is clear that we cannot pass from a spectrum to the other one by a simple scalar multiplication. This operation is enough for the high frequencies ($> f_g$) and can give the good level in time for the acceleration peaks. But for the obtention of the broad-band response spectra, we need also the low frequencies. Thus, intuitively, we see that the function to apply in this case have a dependency with the frequency, i.e., the corresponding distribution of dislocation on the fault plane must have a dependency with the wavelength.

2.3 Dislocation distribution on the fault plane

We want to apply on our dislocation distribution a *similarity constraint. If we consider a fault of characteristic size* L, for a given wave number $k > 1/L$, the similarity implies that the dislocation spectrum $\tilde{\Delta u}(k)$ over L is a constant independent of L:

$$\frac{\tilde{\Delta u}_L(k)}{L} = Constant$$

We have now to find which is the dependency of $\tilde{\Delta u}$ in k. We assume that it is in k^n and we obtain:

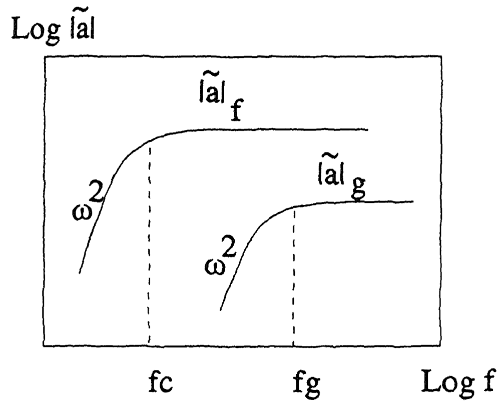

Figure 2. Accelerometric spectra of the synthetic Green function and the expected one for the whole fault.

$$\tilde{\Delta u}_L(k) = CLk^n \qquad (1)$$

with C a constant independent in k and L.

It is enough to study the homogeneity of equation (1) in two dimensions. $\tilde{\Delta u}$ has the dimension of the cube of the length. This implies that the dependency of $\tilde{\Delta u}$ in k is in k^{-2}.

We can also confirm this dependency by comparing the radiated spectra at high frequency and dislocation spectra. With an elementary Heaviside source function, the far-field displacement u at a station is expressed by an integral over the fault surface s of the time derived dislocation $\dot{\Delta u}$:

$$u(t) = C \int_s dxdy \ \Delta u(x,y) \ \delta(t - \tfrac{d}{v}) \qquad (2)$$

C is a constant (units $s.m^{-1}$). In order to simplify the problem, we use the isochrone concept and thus observe the high frequencies. We consider also a particular case where the isochrone cross the fault plane along the x axis parallely to the y axis (figure 3).

In this case, equation (2) simply becomes:

$$u(t) = C \int_0^l dy \ v \ \Delta u(vt, y) \qquad (3)$$

Now, we pass in the frequential space and we obtain:

$$\tilde{u}(\omega) = C \int_0^l dy \ v \ \int_{-\infty}^{+\infty} \Delta u(vt,y) \ e^{-i\omega t} dt \qquad (4)$$

If we introduce in equation (4) $kx = \omega/v$ and $ky = 0$, we relate $\tilde{u}(\omega)$ with the dislocation spectra $\tilde{\Delta u}$:

$$\tilde{u}(\omega) = C \ \tilde{\Delta u}(kx = \tfrac{\omega}{v}, ky = 0) \qquad (5)$$

In high frequency far-field, if we accept the similarity principle on $\tilde{u}$, first introduced by Aki (1967), the radiated displacement spectrum is in ω^{-2}. Thus, from equation (5), we find that $\tilde{\Delta u}$ is in k^{-2}.

3 CALCULATION

The constraint on the dislocation distribution seems satisfying for our purpose. Let us show now a numerical example.

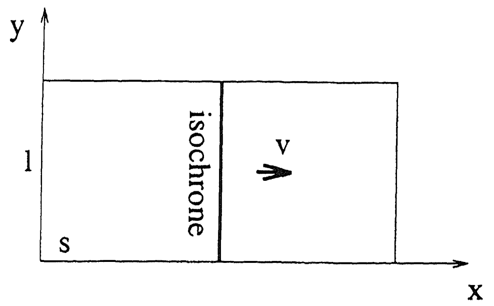

Figure 3. simplified fault model used for comparison between radiated spectra and dislocation spectra.

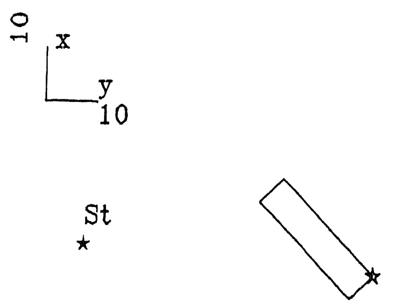

Figure 5. Horizontal projection of the fault and station location. Scales are in Kilometers. The black star represents the station position and the white star points the left low corner of the fault.

3.1 Rupture process characteristics

We have seen that the only condition we have on the dislocation distribution is on the modulus of $\tilde{\Delta u}$. We have to fix the slope of $|\tilde{\Delta u}(k)|$ at -2 in logarithmic scale between k_f, the wave number bounded by the fault characteristic size, and k_g, the wave number associated to the grid spacing. With regard to the phases, we want first to obtain the maximum of dislocation at the center of our fault. For this, we fix in a deterministic way the phases of low wave number in order to obtain a low frequency shape, having its maximum on the center of the fault. Otherwise, the phases of the other points of the dislocation plane in the wave number space are defined in a stochastic way.

For the example, we have chosen a fault with 25.5 Km long(L), 12.7 Km large (l) and a grid spacing of 100 meters along both x and y axis. For k_f, we fix the $|\tilde{\Delta u}(k_f)|/l$ ratio at 5.10^{-5}. This implies a mean stress drop over the whole fault of about $20-30$ bars. The resulting dislocation "topography" is shown in figure 4.

The stochastic phases distribution do not give us a natural decrease of the dislocation to zero on the borders of the fault. We are obliged to tape the distribution in order to force it to become zero on the borders.

The rupture velocity is fixed at 3 Km/s. The S wave velocity is 3.5 Km/s. The nucleation point occurs on a border at three quarters of the width of the fault.

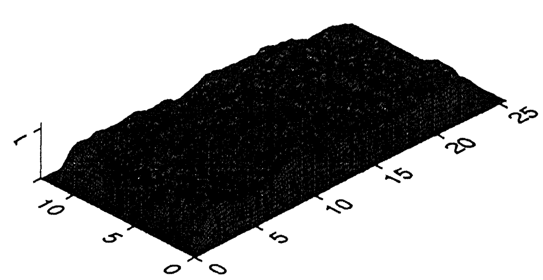

Figure 4. Dislocation topography on the fault plane. Vertical scale is in meters, horizontals ones in Kilometers.

3.2 Station and fault geometry

The mecanism of the fault is (strike 315°,dip 60°, slip −90°). The station is about 40 Km away from the source. The rupture is NorthEastward and propagates toward the station St(figure 5).

3.3 Acceleration modeling

We calculate the S wave acceleration at the station. The north component with its spectrum is shown in figure 6. The duration is short due to the directivity of the chosen geometry. The acceleration peak at 17.5 s correspond to the stopping phase on the top

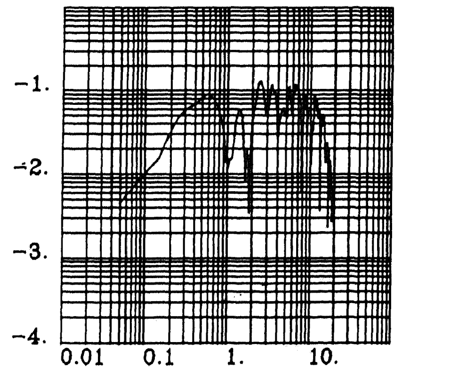

Figure 6. North component acceleration. The amplitude is in $m.s^{-2}$ for the accelerogram, in $\log[m.s^{-1}]$ for the spectrum.

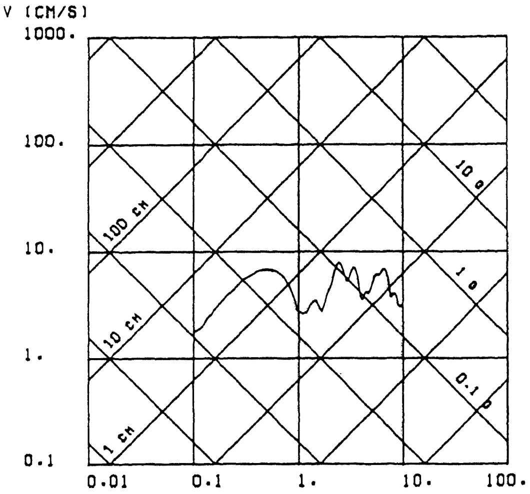

Figure 7. Relative velocity response spectrum.

border of the fault. The spectrum has a good shape in ω^2: we obtain the expected plateau after the corner frequency (0.5 Hz), the high frequency fall off after 10 Hz being produced by the rise time.

A remarkable feature are the holes in the spectrum at 1 and 2 Hz. They should be correlated to the geometry of the fault. There frequencies are too high to be related at the characterictic sizes of the source. Anyhow, this feature is also observed sometimes on recorded data, notably in teleseismic records where some holes in the spectrum after the corner frequency are observed. The tape effect could be a explanation but this feature need more studies and the discussion keeps open on this point.

The broad band synthetic accelerogram allows us to compute a velocity response spectrum up to 10 Hz. The spectrum at 0.05 damping pourcentage is shown in figure 7. Of course, the holes observed on the acceleration spectrum also appear here. Thus, it is important now to determinate there origins and eliminate there undesirable effects in a seismology engineering statistic point of view.

4 CONCLUSION

The results presented here are still preliminary. We have seen that the method is determinist for the global trend (mecanism, distribution laws...) and stochastic for the details (phases).

The problems of such model for instance are the distribution of phases and the dynamic aspect. The phase distribution does not give a natural zero on the fault borders. Thus, the distribution is not completly stochastic. We have to find the constraints which allow us to eliminate the tape and its effects on the spectra. For a dynamic point of view, our model is not correct. We know that the $\Delta u/\tau$ ratio is approximatively constant in general on the fault plane, which means that τ may be much larger than 0.05 s. If we apply this, we eliminate the high frequency plateau and obtain a fall off. In other hand, assuming that velocity rupture is constant is probably also incorrect. The rupture can stop abruptly and after some time, restart at a quasi shear wave velocity, creating important acceleration radiations. As the high frequency plateau is an observation, we have to find the variation of the rupture velocity which would anihilate the effect of the rise time if we want a dynamic aspect in our model. However, we may consider that kinematic model correctly simulates the global effect of rupture velocity and rise time fluctuations. The advantages of our model on spectral methods are in one hand the temporal shape which have correct envelop and in other hand, its applicability to station near a seismic source. More, this method could lead easily to modeling based on empirical Green functions by its formulation itself (synthetic Green function) and it may be of great interest for working in a given neotectonic context in order to evaluate seismic hazard.

REFERENCES

Aki, K. 1967. Scaling law of seismic spectrum. *J. Geophys. Res.* 72: 1217-1231.

Bernard, P. 1987. Du caràctère complexe et agressif des sources sismiques. Thèse de Doctorat d'état, Univ. of Paris, Jussieu. Paris.

Bernard, P. & R. Madariaga 1984. A new asymptotic method for the modeling of near-field accelérograms. *Bull. Seism. Soc. Am.* 74: 539-559.

Boore, D. M. 1983. Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra. *Bull. Seism. Soc. Am.* 73: 1865-1894.

Brune, J. N. 1970. Tectonic stress and spectra of seismic shear waves from earthquakes. *J. Geophys. Res.* 75: 4997-5009.

Fukushima, Y. & T. Tanaka 1990. A new attenuation evaluation relation for peak horizontal acceleration of strong earthquake ground motion in Japan. *Bull. Seism. Soc. Am.* 80: 757-783.

Mohammadioun, B. & G. Mohammadioun 1980. Analyse de données sur les mouvements forts actuellement disponibles. C.E.A., D.E.S.N.. France.

Petrovski, D. 1986. Probabilistic approch for evaluation of seismic design parameters. Specialist meeting on earthquake ground motion and antiseismic evaluation of nuclear power plant. Moscow, U.S.S.R.

Spudich, P. & L. N. Frazier 1984. Use of ray theory to calculate high-frequency radiation from earthquake sources having spatially variable rupture velocity and stress drop. *Bull. Seism. Soc. Am.* 73: 2061-2082.

Yoshida, S. 1986. A method of waveform inversion for earthquake rupture process. *J. Phys. Earth* 34: 235-255.