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SIMULATING GROUND MOTION IN GRENOBLE BASIN BY COUPLING GROUND MOTION PREDICTION EQUATIONS AND THE EMPIRICAL GREEN'S FUNCTIONS METHOD

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ABSTRACT - We propose a new approach to perform reliable seismic ground motion predictions for a future earthquake: (1) we generate a large population of response spectra on rock site (the reference site) by using a kinematic EGFs method and varying the future event rupture parameters; (2) we also simulate response spectra on reference site at several fractiles, using ground-motion prediction equations of Ambraseys et al. (2005) corrected according to the site-specific rock conditions; (3) we perform an inversion process to select the EGFs simulated response spectra corresponding to these fractiles; (4) resulting EGFs summation schemes are applied to sediment site recorded EGFs. We finally obtain wedged medium ground motion on specific sediment sites and a standard deviation in agreement with the ground-motion prediction equations of Ambraseys et al. (2005).

1. Introduction

Simulation of realistic seismic ground motion produced by an hypothetical future earthquake is of main importance to predict potential damages. This is particularly true in alpine valleys where moderate earthquakes may have large consequences caused by large site effects. However, in such areas, the lack of detailed knowledge of the medium properties is a curb on using numerical methods for estimating ground motion in a relevant frequency range for earthquake engineering [0.1 – 20 Hz]. Moreover, ground motion prediction equations are not able to properly account for specific 2D/3D site effects. An alternative approach is then to use the empirical Green's functions (EGF) method (Hartzell [1978]), whose principle is to sum up delayed small earthquakes recordings. Each of those last contain all the information about propagation and site effects between source and receiver. These effects are then automatically accounted for under, however, the strong assumption of the linear behaviour of the medium. This method is also valid under far field conditions only.

Several approaches of the EGF method have already been developed and successfully applied for site-specific ground motion modelling (Hutchings [1994]; Bour and Cara [1997]; Kohrs-Sansorny et al. [2005]). The difference between these approaches lies in the way the summing up of the EGFs is performed : with kinematic description of the rupture (kinematic methods) or without (stochastic methods). Kinematic methods are more attractive since time delays between the EGFs are generated by a physically realistic rupture process across the hypothetical fault. In many papers, the simulated event is already known: the parameters characterising the rupture are then adjusted to obtain the best agreement between simulated and recorded ground motion. More difficult is to estimate the rupture process parameters and their related uncertainties to assess ground motion and its variability for an unknown future earthquake. Pavic et al. (2000) proposed an EGF technique to assess uncertainties of ground motion predictions. First, the "input parameters" uncertainties are determined by means of an international expert inquiry. Second, the repercussions of these uncertainties on the simulated ground motion are calculated by using the Latin Hypercube Sampling method (McKay et al., 1979). Nevertheless, the large variability derived from analysis of the experts opinions pointed out the difficulty in choosing appropriate distribution laws for input source parameters. To overcome this delicate stage, we propose to adapt the Pavic et al. (2000) approach by using empirical ground motion equations: (1) we generate a large population of response spectra at rock site (the reference site) using the EGF summing up process for different rupture parameters; (2) we simulate response spectra on reference site corresponding to different fraciles by using empirical ground motion equations; (3) we select simulated response spectra that best fit predicted response spectra; (4) resulting EGF sommation schemes are then applied to recorded EGFs at sediment sites. Finally, we obtain the median and the standard deviation of predicted ground motion in agreement with the empirical motion equations on rock sites.

In the first part of this paper, we present a simple EGF approach to realize the "imposed" ground motion predictions within the framework of the "Numerical Benchmark of 3D ground motion simulation in the valley of Grenoble, French alps". In the second part, we describe our new method, which we used to achieve the "freestyle" predictions of the benchmark. For both "imposed" and "freestyle" predictions, ground motion is simulated within the frequency range [1 – 40 Hz], that corresponds to a signal-to-noise ratio above 2 for the EGFs. Since focal mecanisms of both EGF and target event are different for the S2 case, we have only simulated the S1 case, which corresponds to a M_w 6 earthquake occuring about 10 km east from the Grenoble city.

2. "Imposed exercice"

2.1. Outline of the method

We define simulated ground motion *S(t)* in the temporal domain as

$$S(t) = R(t) * s(t) \tag{1}$$

where *s(t)* is the EGF and *R(t)* is the apparent source function describing the number and the way to sum up the EGFs. Following the approach of Pavic et al. (2001), the number of added events is deduced from the scaling relations of source parameters (Brune, 1970) and source spectra (Aki, 1967). Assuming a constant stress drop between both small and target events, the number of added EGFs is then

$$M_0 / m_0 = N^3 = N_L \cdot N_W \cdot N_D \tag{2}$$

where N_L, N_W and N_D are the numbers of EGFs to sum up along the length of the fault plane N_L, along the width N_W and in the temporal domain N_D, respectively. First we split the target fault plane into $N_L \cdot N_W$ squared subfaults. Second, as the static slip and the rise time T_d are supposed to be spatially uniform, we sum up N_D EGFs in the temporal domain on each subfault. The different sources of time delays used in the summation of the EGFs are then path length, rupture propagation and dislocation rise time processes.

1.2. Assessment of the apparent source function

1.2.1 Theoretical apparent source function

From equation (1), the apparent source function is defined in the frequency domain as:

$$R(\omega) = S(\omega) / s(\omega) \tag{3}$$

The usually assumed ω^{-2} spectral decay and the classical scaling law of the form $M_0 \sim L^3$ for a constant stress drop (Aki, 1967) allow us to define the theoretical Fourier displacement spectra of both small and target events and the spectral ratio *R(ω)* (figure 2).

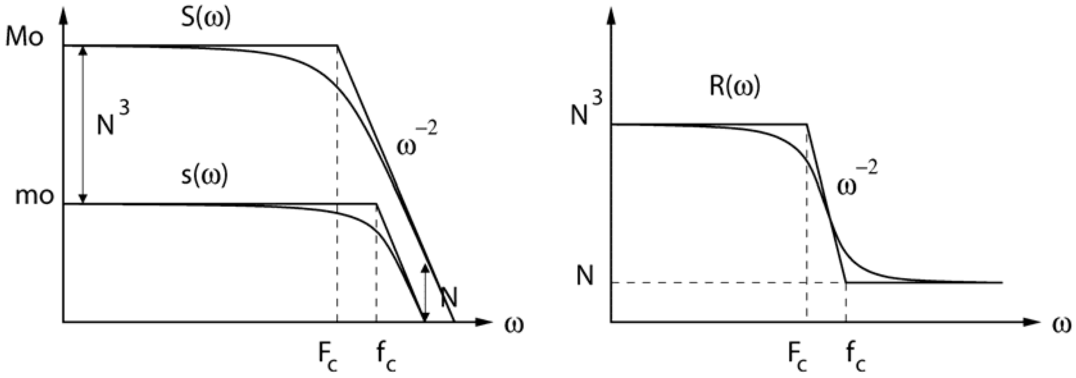

Figure 1. (Left) theoretical Fourier displacement spectra of the EGF and the target event; (right) theoretical apparent source function spectrum R(ω).

1.2.2. Determination of the source time function

Although recent studies on earthquakes kinematic (Mai et al., 2004; Manighetti et al., 2005) have shown that static slip distributions are far from being uniform, an uniform slip distribution has been imposed in this study for sake of simplicity. Moreover there are evidences that earthquakes do not always nucleate at the middle of the rupture plane. In order to be in agreement with the simple imposed kinematic, we decided to use a simple source time function to describe the slip rise time processes. The use of a basic ramp function would generate spurious high frequencies in the source function spectrum, due to the regular duplication of the local slip functions of the small event (Bour et Cara, 1997; Kohrs-Sansorny, 2005). Instead of summing up N_D regularly spaced events on each subfault, we then suggest to distribute them uniformly in the interval $[0,T_d]$. Nevertheless the summing up of the EGFs is coherent in the low frequency part and incoherent in the high frequencies, leading to a high frequency level scaling as $(M_0/m_0)^{1/2} = N^{3/2}$ instead of N (Figure 2). To obtain the expected level, we consequently sum up N^4 EGFs, i.e. $N_D \cdot N$ EGFs in the temporal domain and next divide the source function spectrum by N. This process, developped by Korhs-Sansorny et al. (2005), allows to obtaining both low and high frequency levels in agreement with the theoretical model. While matching expected low and high frequency levels is feasible, obtaining a ω^{-2} spectral decay in the mid-frequencies with the imposed simple kinematic remains more difficult. Indeed, we obtain an underestimated spectral ratio in this frequency range (Figure 2). Instead of searching the source time function formulation that results in the best agreement between both theoretical and simulated apparent source functions in the mid-frequencies, we keep our simple formulation and introduce a more adapted kinematic for the "freestyle" predictions.

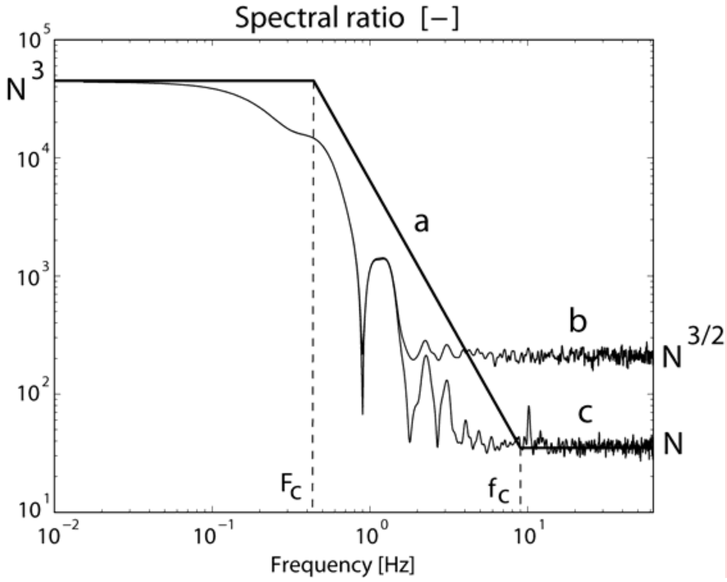

Figure 2. a : Theoretical source function spectrum; b : average source function spectrum for a classical N^3 sommation process; c : averaged source function spectrum for a N^4 sommation process.

2. "Freestyle" predictions for Grenoble basin

2.1. Method

EGFs summing up process is the one presented in Pavic et al. (2000). The adopted source model is a Kostrov crack model. Hutchings (1994) showed that it automatically leads to a ω^{-2} spectral fall-off. Figure 3 shows an example of resulting source function spectrum. The main considered source parameters are target event stress drop, rupture velocity and rupture nucleation location. However it remains almost impossible to assess accurately their related uncertainties and their effects on simulated ground motion. Therefore we propose to simulate with the EGF technique ground motion on rock (OGMU station) whose median and standard deviation values agree with predictions of empirical ground motion equations. Here we choose the model developed by Ambraseys et al. (2005) that enables to derive median value and standard deviation of spectral acceleration, following a lognormal distribution. A correction procedure (Cotton et al., 2006) is applied to account for specific rock conditions at OGMU station, where V_{S30} is supposed to be equal to 1000 m/s (P. Gueguen, personal communication). This value differs from the expected average value of 800 m/s for rock site stations used in the Ambraseys et al. (2005) model. The two main stages of our approach are then: (1) to fix first median ground motion on rock and then on sediment; (2) to determine ground motion variability in agreement with the corrected model of Ambraseys et al. (2005).

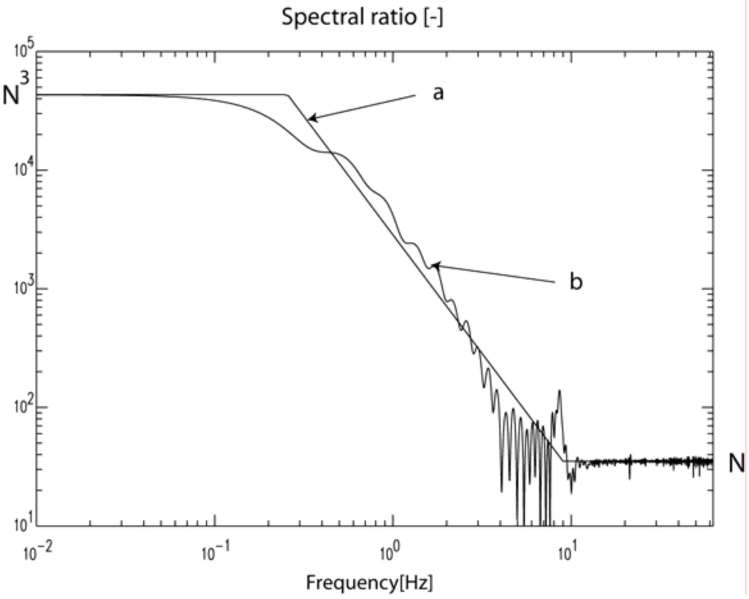

Figure 3. a. Theoretical source function spectrum. b. Simulated source function spectrum for a Kostrov model. The coordinates of the nucleation point are (L/2,W/3), the rupture velocity is 2.7 km/s and the stress drops for both small and main events are equal. The peak occuring at 10 Hz is due to the finite distance between the small-event sources and the supposed constant rupture velocity.

2.2. Computation of median ground motion

The first aim is to characterize the source parameters which lead to median ground motion. On the one hand, we use the ground motion prediction equations in order to calculate ground motion at OGMU rock site. Resulting response spectrum is taken as the “reference“ ground motion at OGMU station. On the other hand, we generate a large population of response spectra using the EGFs technique of Pavic et al. (2000) with varying source parameters. The range of source parameters are indicated in Table I. The recent study of Mai et al. (2005) led us to constrain the rupture nucleation location and consequently to reduce the number of potential values. The parameters values are combined by means of a simple grid algorithm, conducting to a number of 10050 parameters sets.

Table I. Variation ranges of source parameters. Parameter values are regularly spaced within these intervals. L and W are the fault length and the fault width, respectively

Parameter	Stress drop (Bars)	Rupture velocity (km/s)	Rupture nucleation X-coordinate	Rupture nucleation Y-coordinate
Variation interval	10-1000 Bars	2.5-2.9 km/s	1/11*L-10/11*L	0.3*W-0.5*W
Number of possible values	70	5	10	3

Finally, the best simulated median ground motion at rock site is selected by finding the one with the lowest misfit – in a least square sense – to the predicted median response spectrum (Figure 3).

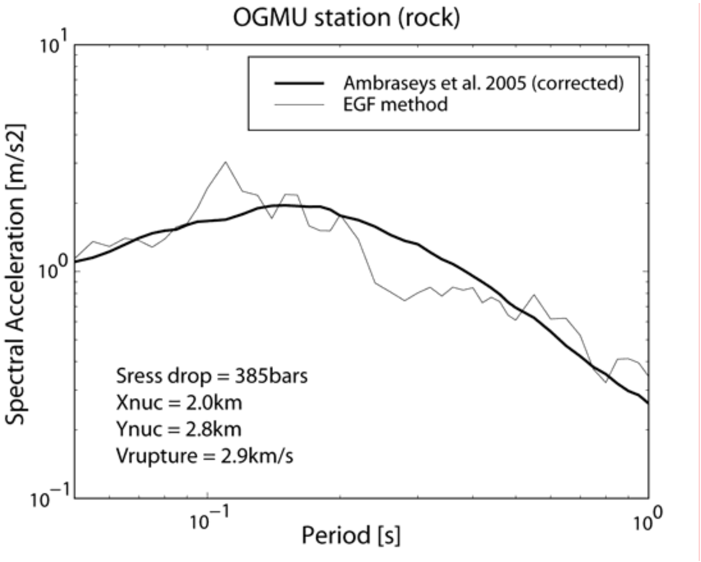

Figure 4. Median response spectra at OGMU station (maximum of the horizontal components). The source parameters used in the EGFs method are indicated (stress drop, position of the rupture nucleation on the fault plane and rupture velocity respectively).

We next compute ground motion on sediments at station OGFH by using the parameters set related to the best simulated median ground motion at rock site and the EGFs recorded by these stations (Figure 4). Figure 5 shows the comparison between simulated response spectrum and spectrum obtained from Ambraseys et al. (2005) model for sediment sites. This comparison point out that ground motion prediction equations are inappropriate to account for all the complexity of site effects in the 3D Grenoble basin.

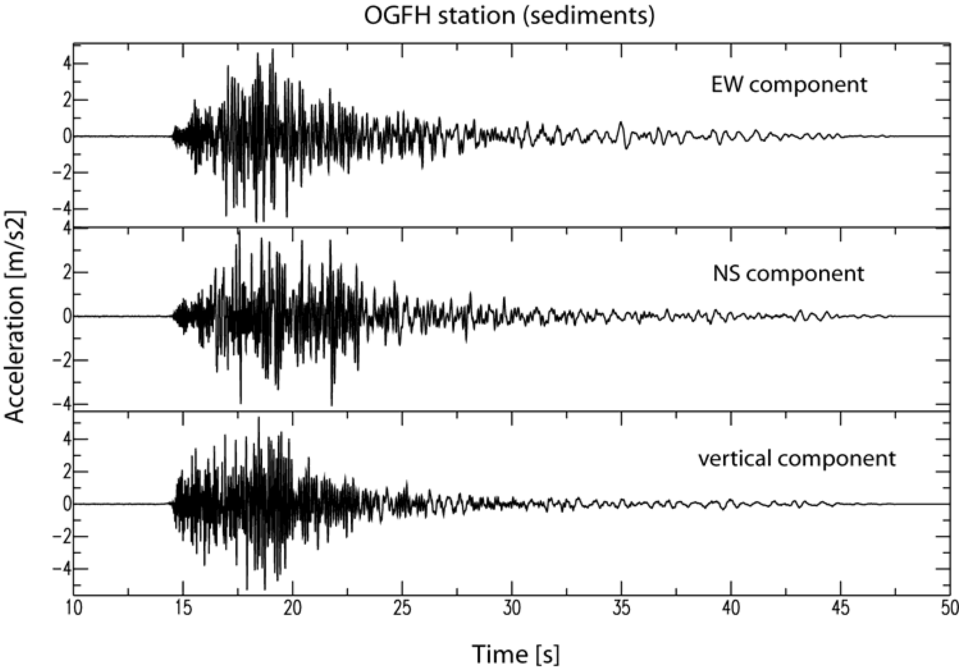

Figure 5. Simulated median ground motion on sediments (OGFH station).

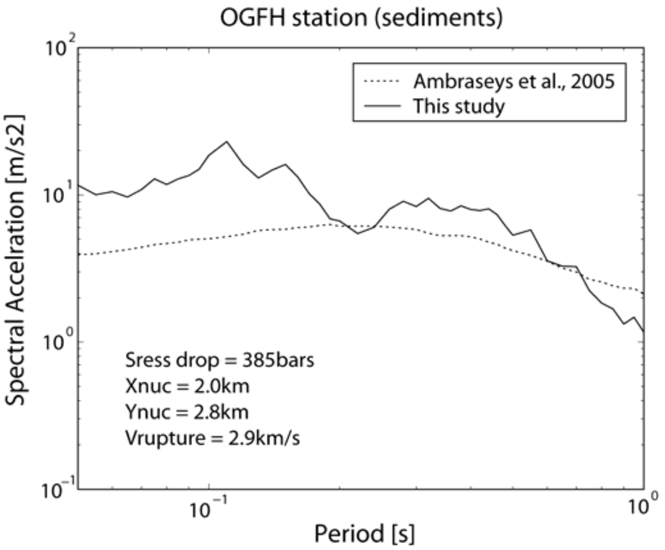

Figure 6. Median response spectra at OGFH station (maximum of the horizontal components). The source parameters used in the EGFs method are the same as in figure 3. We show the comparison with the predictions of Ambraseys et al. (2005) on sediments.

2.3 Assessment of ground motion variability

We propose a simple technique to obtain a ground motion variability in agreement with the ground motion prediction equations of Ambraseys et al. (2005) (corrected model). The intra-earthquake variability proposed in ground motion prediction equations of Ambraseys et al. (2005) is supposed to be a good approximation of the ground motion variability observed in nature, *e.g.* due to the unpredictable nature of a unique earthquake. In order to simulate ground motion variability in agreement with the ones given by ground motion equations, we first compute 10 “reference” response spectra on rock corresponding to different fractiles (5%, 15%,..., 95%) using the prediction equations. Fractiles are indeed chosen such as for a given period, standard deviation values computed from the 10 corresponding spectral acceleration values (after Ambraseys (2005) equations) are the same as those given by the prediction equations. Second, following the process described in part 2.1, we determine simulated response spectra which best match the 10 “reference” response spectra. Resulting source parameters (Table II) are next used as input parameters to simulate by using EGF method a set of 10 response spectra at the target site OGFH. For a given period, spectral acceleration standard deviation is then computed from the 10 corresponding values (Figure 6).

Table II. Source parameters sets leading to the chosen fractiles.

Fractiles (%)	5	15	25	35	45	55	65	75	85	95
Stress drop (Bars)	70	115	160	670	670	520	685	865	940	925
Rupture velocity (km/s)	2.8	2.8	2.6	2.9	2.9	2.9	2.8	2.9	2.9	2.5
Xnuc (km)	2.8	5.0	4.0	2.0	2.0	3.0	3.0	3.0	4.0	5.0
Ynuc (km)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	1.7

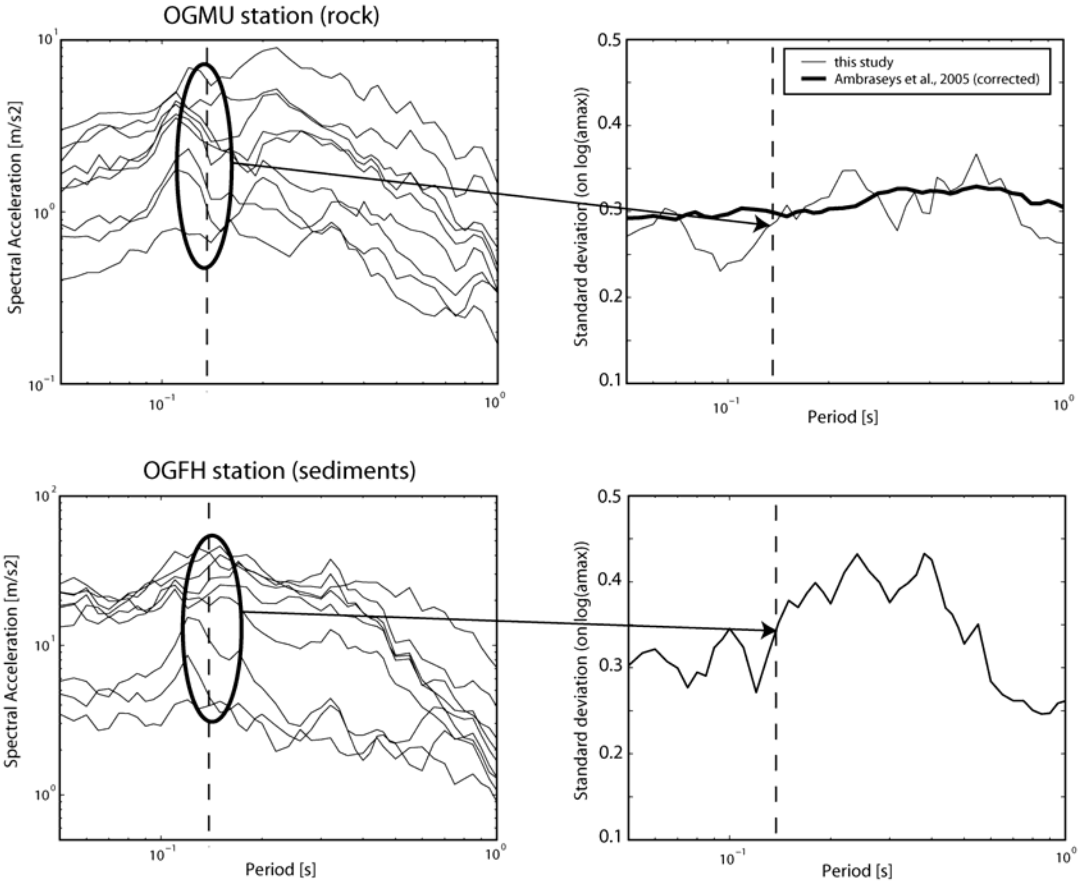

Figure 7. Computation of standard deviation on rock and on sediment. (Left) response spectra for fractiles 5%, 15%,…,95%; (right) resulting standard deviation values.

3. Discussion

The selection of the empirical model used as “reference” ground motion remains a delicate stage. In particular, the publications in which the equations are presented generally include relatively little of the source information on which the site classifications are based, which hampers the interpretation of the defined rock category. Thus it might be incorrect to compare rock site conditions of Ambraseys et al. (2005) equations to rock type at OGMU station. Moreover the applied correction only concerned the first 30 meters under OGMU station and V_{S30} value at this site is poorly known. This value may be overestimated. This could explain some apparently aberrant values obtained for the target event source parameters. For instance the simulated event stress drop value leading to median ground motion on rock reaches 385 Bars, which seems widely overestimated.

4. Conclusion

The EGF method is an attractive ground motion simulation method, especially through its ability to naturally account for site effects. However, this method is difficult to apply when source parameters are not known. In order to simulate ground motion in the Grenoble basin after a M_w 6 earthquake we proposed to combine the EGF method of Pavic et al.

(2000) and ground motion prediction equation of Ambraseys et al. (2005) to wedge the median simulated ground motion and its variability on rock. Nevertheless the choice of the ground motion equation still remains delicate, espacially due to the lack of knowledge of the rock conditions used to derive the equations and of the “reference” rock site used in our method.

5. Acknowledgements

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