A STUDY ON THE LONG DURATION OF GROUND MOTION IN THE GRENOBLE BASIN, FRENCH ALPS

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ABSTRACT :

The city of Grenoble in the French Alps is settled on top of hundreds of meters of post-glacial sediments which cause ground motion to be significantly increased in terms of amplitude and duration. Here, we present analyses focused on the ground motion duration observed in the Grenoble valley for 3 well recorded local events with magnitudes M2.8, M2.9 and one regional event with magnitude M4.4. The analysis is performed in terms of energy duration (based on ground velocity) and Arias duration (based on ground acceleration) for frequencies between 0.5 Hz and 15 Hz. We find that the observed duration is controlled by low frequencies, i.e. less than 3 Hz for local (d<20 km) small (M2.8, M2.9) events and less than 2 Hz for the regional (d=150 km) larger (M4.4) event. For the regional event we observe a slight correlation between duration and sediment thickness on the vertical component. Assuming a simplified 3D model of the valley derived from gravimetric studies and borehole measurements, numerical simulation of those local events with the spectral element method successfully explains the level of observed amplification for frequencies up to 2 Hz but fail at predicting such values of lengthening of duration, unless considering unrealistic quality factors in quaternary sediments. The reason why the available model of the Grenoble valley does not explain the observed duration is further discussed in terms of weathered rock formation, intrinsic attenuation, and shallow velocity structures.

KEYWORDS: Ground Motion, Duration, Energy, Grenoble basin, The French Alps, Laffrey2005

1. INTRODUCITON

The Grenoble basin (Figure 1) is located in the west of Belledonne Border Fault that an earthquake occurs frequently and has a Y-shaped configuration. In recent years several local events (Mw 3) and regional events (Mw 5) happened around the Grenoble basin. Simulation of Laffrey2005, which is one of the local events observed so far, was performed for the first time by Chaljub (2006), but he was not able to reproduce extraordinary long duration waveforms of recording data at several sites in the basin.

Therefore we use data of two local events and its simulation (Laffrey2005, Lancey1995, simulation of Laffrey2005 by Chaljub, 2006) that occurred near the Grenoble basin (Figure 2) and one regional event (Vallroncine2005) 150 km away from the basin in this study and analyze energy duration and Arias duration of them. We would like to clarify how the observed long duration of the Grenoble basin is emerged and what is the cause of it by using a current 3D basin model estimated by gravimetric studies and borehole measurements. Through this kind of study for observed motions we can construct a better basin structural model, which can be used for strong motion simulation for future events around the Grenoble basin.

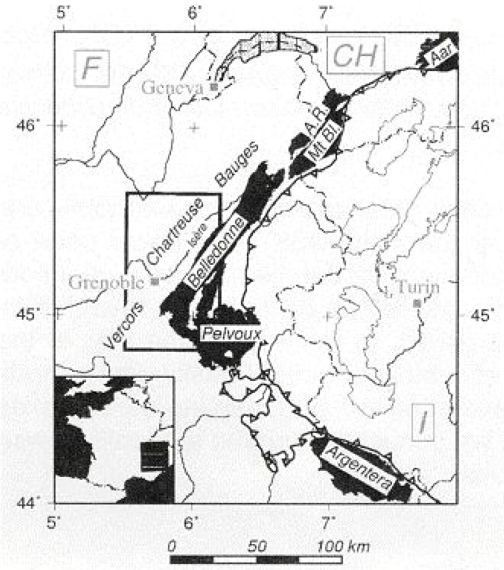


Figure 1. Location of the Grenoble basin and its tectonic environment (after Thouvenot, 2006).

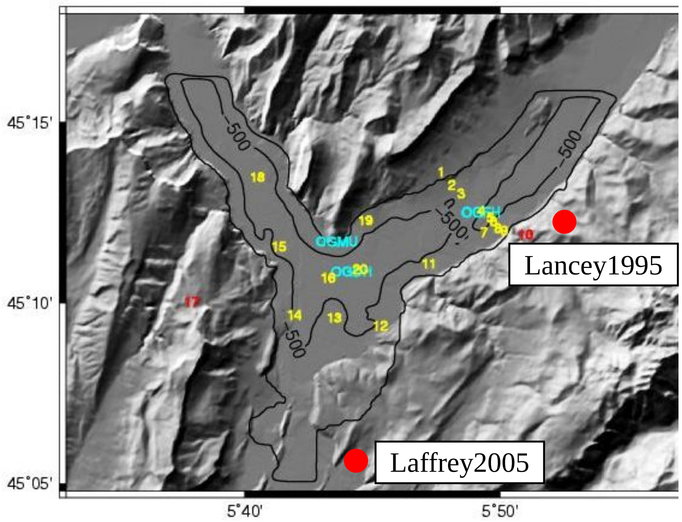


Figure 2. Topography and basin depth contour, together with epicenters (red circles) of two local events (after Thouvenot, 2006).

2. OBSERVED DURATION

In this study, durations of observed waveforms are based on the definition by Husid (1969). Energy is the integral of squared velocity time histories and energy duration is time with 95% of the total energy subtracted by time with 5 % of the total energy (Figure 3). We calculated energy and energy duration and also Arias intensity and Arias duration for acceleration waveforms.

Energy; $$E(t) = \int_0^t V(\tau)^2 d\tau \qquad (1)$$

Energy duration te=t2(95%)-t1(5%) (2)

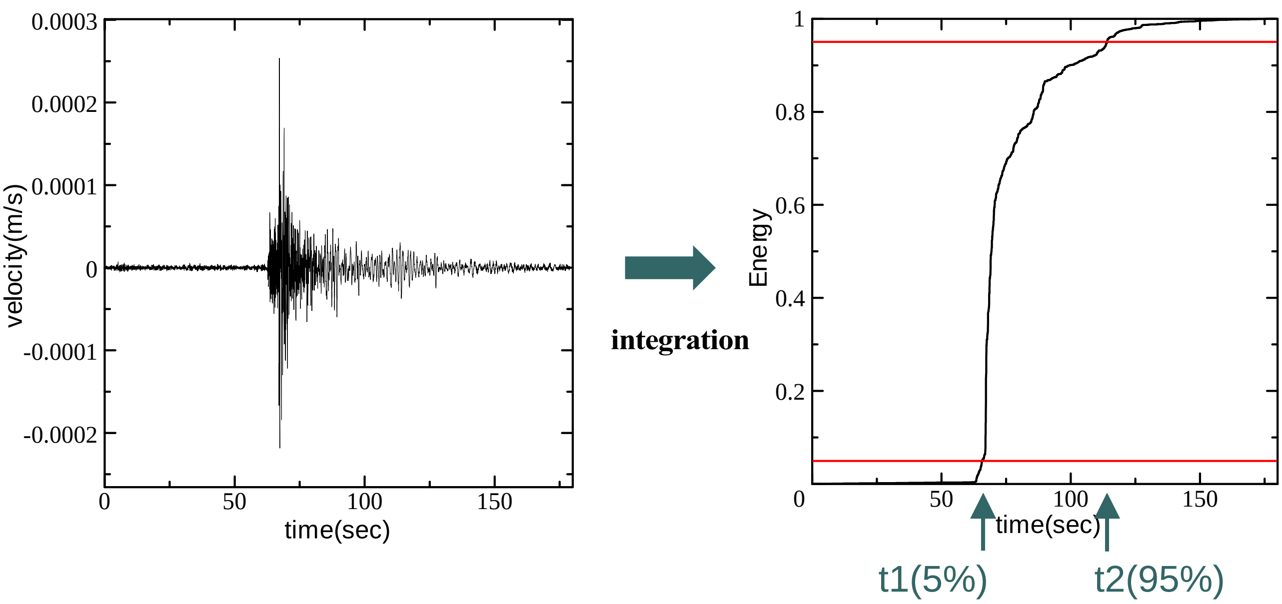


Figure 3. Calculation of velocity duration based on the proposal of Husid (1969).

3. PROCEDURE OF DATA ANALYSIS

First, we have to remove noises from recorded data for accurate extraction of energy duration and energy. We considered waves recorded before the arrival of P wave as noises (N) and considered waves after the onset of P-wave as signals (S) and calculated the spectrum ratio between them (the S/N ratio). After we choose the record section to analyze, we add tapers on both sides of the target recorded sections. We check frequency band in which S/N ratio is larger than 1 for all recorded data and then decide the appropriate frequency band by which band pass filter is applied. Within that range several different band pass filters are used to know the duration characteristics for different frequency ranges. For such analyses the low cut-off frequency is fixed to be 0.4Hz and high cut-off frequency is changed to be 0.5Hz, 1Hz, 2H, 3Hz, … , up to 15Hz. The data that we used are from two local events (Laffrey2005, Mw2.8; Lancey1995, Mw2.9) and one regional event (Vallroncine2005, Mw4.4). We applied the same analysis method to the 3-D spectral element method simulation data of Laffrey2005 by Chaljub (2006), which is valid up to 2Hz.

4. RESULTS OF OBSERVED DURATION ANALYSIS

We calculated energy and energy duration of velocity seismograms by the procedure that we showed in Section 2, and also Arias intensity and Arias duration of acceleration seismograms obtained from observed velocity seismograms. First, we compare energy duration in all the stations by two earthquakes (Laffrey2005 and Valloncene2005) as shown in Figure 4. Note that the stations that we measure Lancey1995 are different from those for the other two earthquakes. As a result, we can see that as a general tendency sites on the sediments show larger energy duration and that for Laffrey2005 event energy durations at stations set up in a line-shaped array in northeast area of the Grenoble basin are significantly longer than other stations, although their integrated energies themselves are not so large. On the other hand, such a remarkable phenomenon is not seen in the records of the other two events. The same is true for Arias intensity and Arias duration, that is, sites on the sediments tend to have larger values but there are no sites with significantly large Arias durations.

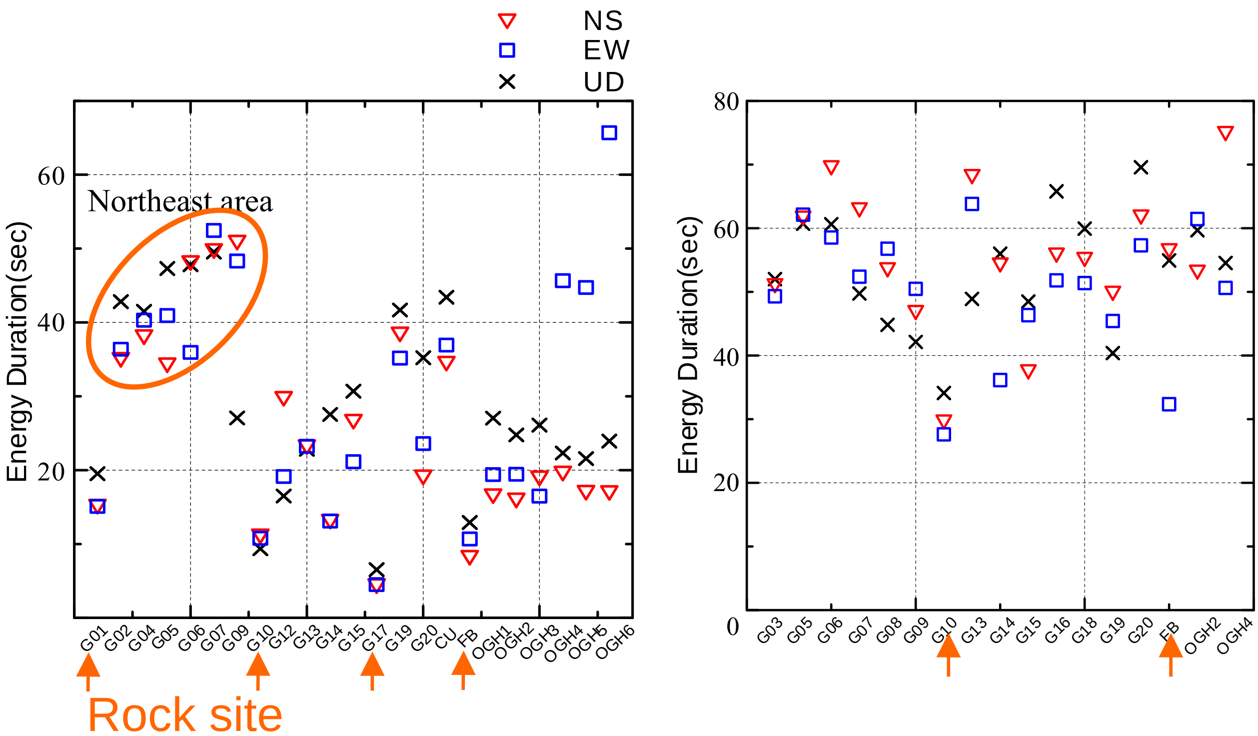


Figure 4. Energy durations of observed velocity seismograms at all the sites in and around the Grenoble basin.

Second, we compare energy and energy duration in every frequency band for all the three events. Figure 5 shows velocity waveforms (top) and energy duration (middle) and energy (bottom) in each frequency band at the station G06 EW components for Laffrey2005 and Valloncene2005 or MEYL EW component for Lancey1995. As for velocity waveforms, top red lines show no-filtered waveforms and black lines show filtered waveforms (from the top fmax, high cut frequency of the band-pass filter is 0.5Hz, 1Hz, 2Hz, …, and 10Hz). As a result, it is shown that up to 2Hz it is the important frequency band that almost determines energy duration for local events (Laffrey2005 and Lancey1995). On the other hand, it is up to 3Hz for a regional event (Vallroncine2005). As for energy, relatively lower frequency is similarly significant for Vallroncine2005 than for Laffrey2005 and Lancey1995. The similar results are obtained for acceleration data with Arias intensity and Arias duration, but much lower frequency is significant on determination of duration of acceleration than velocity. It seems that the differences of significant frequency bands for duration and energy on each event may be related to their magnitude, but we need more data to confirm the inference.

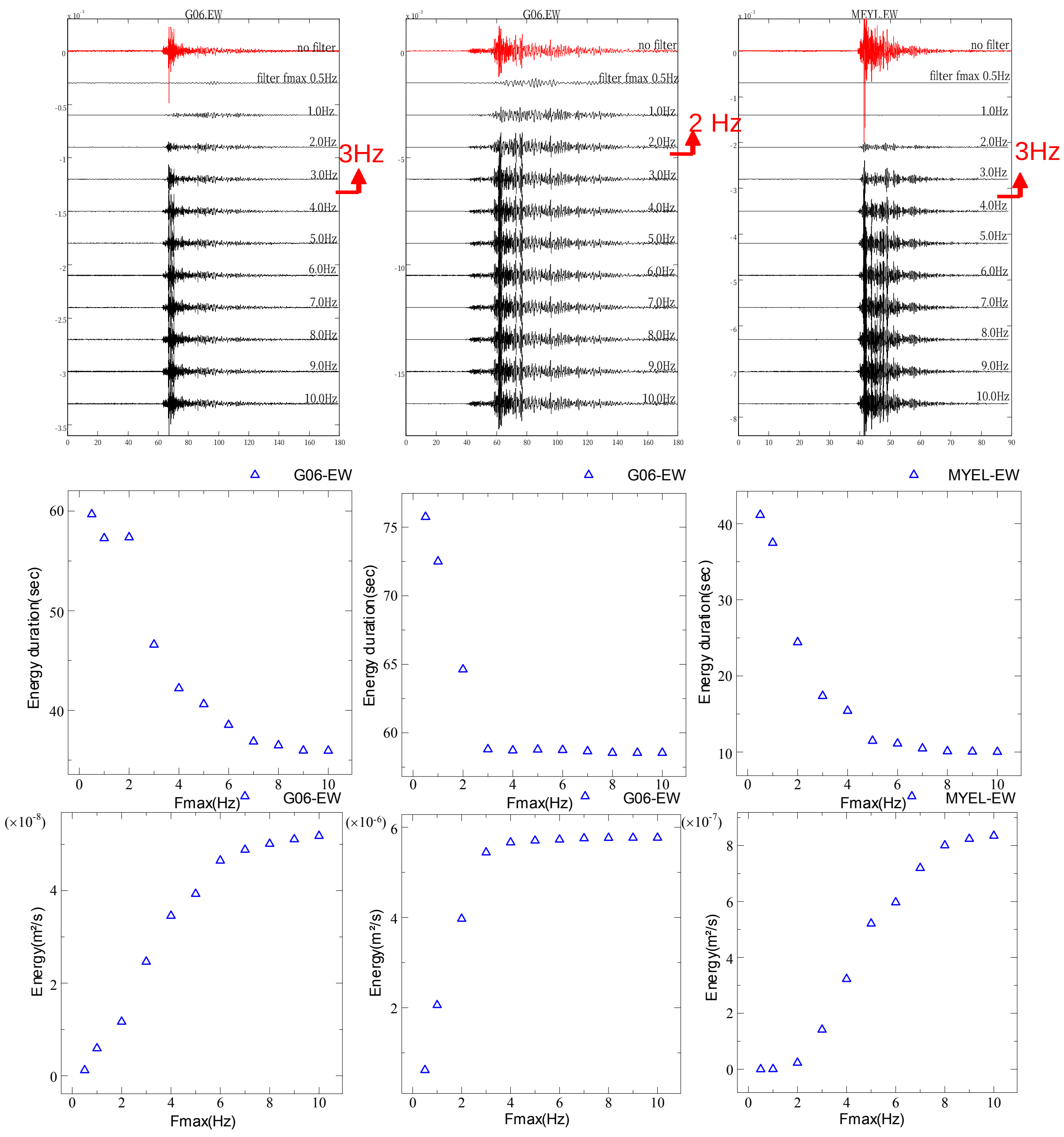


Figure 5. Filtered velocity seismograms, their energy durations and energies as a function of high-cut frequency.

Next, we focus on relationships between bedrock depths of stations and energy durations or Arias durations. As shown in Figure 6, we can see good correlation between bedrock depths and duration on only the UD component observed for Vallroncine2005, where energy durations and Arias durations are longer for deeper bedrock depth sites. We cannot find similar levels of correlation on any of horizontal components of Vallroncine2005 and any components of the other two events.

Lastly, we compare energy duration for EW components of Laffrey2005 event and their simulations up to 2Hz by Chaljub (2006), as shown in Figure 7. There are two simulations by Chaljub (2006); one with Q value in the basin set to be 50 and the other 200. Q50 case is more realistic than Q200 case, however, durations of observed data (▽)are larger than those of simulation data with Q50 at most of the stations. Observed energy is similarly much larger than the simulation with Q50. We can not see good agreement even at rock sites where no influence of surface deposits exists. It is necessary to reconsider the deep ground structure of the whole Grenoble basin including surrounding rock as well as the source characteristics.

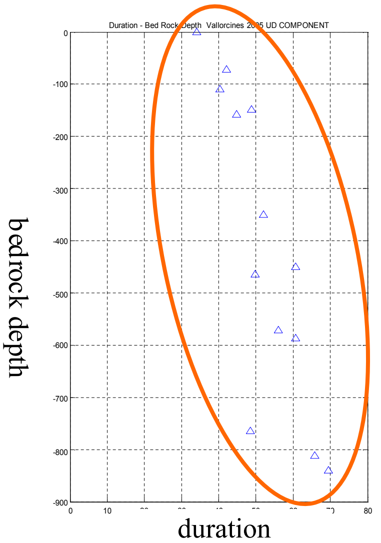


Figure 6. Correlation between durations and bedrock depths .for UD components of records for Valloncene2005.

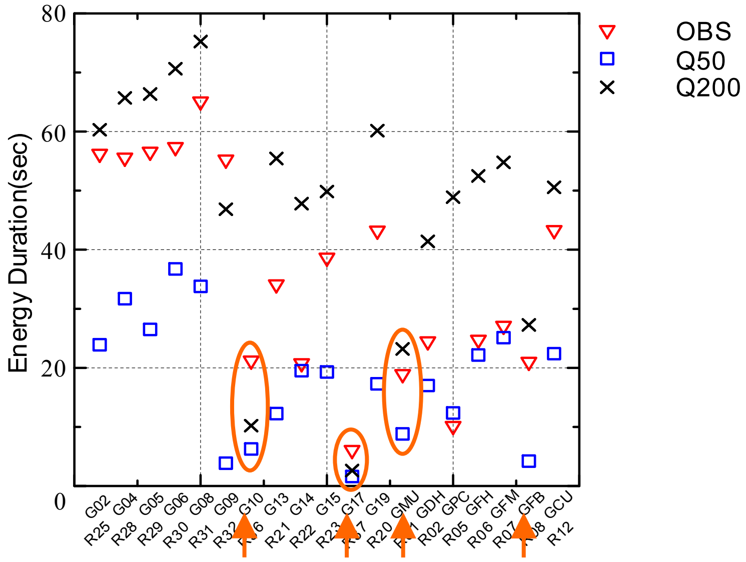


Figure 7. Comparison of energy durations of simulations with two different Q values by Chaljub with observations for Laffrey2005.

5. SIMULATION FOR LAFFREY2005

5.1 Method of Simulation

To reconsider a current 3D model of Grenoble basin, we perform a parametric study for Laffrey2005. Analysis area is 30km (EW direction) by 37.5km (NS direction) by 10km (depth) and the control point is chosen at a north-west corner (5.589069°E, 45.29908°N). We use 3D-FDM tool called "GMS" developed and distributed by NIED (Aoi and Fujiwara, 1999) up to 2Hz. Ground structure model is based on Chaljub (2006)'s model estimated by gravimetric studies and borehole measurements and linear interpolation in 125m mesh is applied to put the Chaljub's basin structure into GMS (Figure 8). In the velocity structure inside the basin, we divide the sediments into four layers from the surface

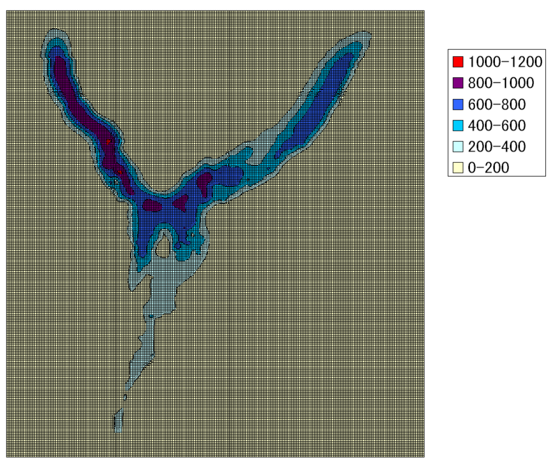


Figure 8. Depth contour of the Grenoble basin

Table1. Underground structure

No.	max-depth(m)	Vp(m/s)	Vs(m/s)	ρ (kg/m3)	Q
1	132	1525	500	2148	50
2	265	1675	560	2163	50
3	531	1900	668	2189	50
4	1063	2350	820	2234	50
5	3000	5600	3200	2720	infinity
6	10000	5920	3430	2720	infinity

Table2. Source parameters

longitude	latitude	depth(m)	strike	dip	rake	Mo(Nm)
5.025	45.75	3000	160	90	180	1.99+E13

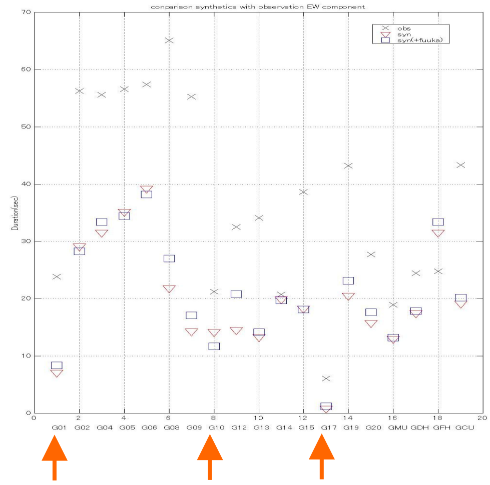


Figure 9. Simulated energy duration for models without (▽) and with (□) a weathered layer in comparison to the observed record (X) for Laffrey2005. Orange arrows indicate rock sites.

with the thickness of 1/8, 1/8, 1/4, 1/2 because we were not able to model a velocity gradient structure. Topograhic features are not considered in this calculation. We used velocity waveform, duration, energy, Fourier spectrum, and RMS envelope for comparison between observed data and synthetics. Time window width of the moving average for RMS envelope calculation is set to be 2 seconds.

5.2 Result of Simulation for Laffrey2005

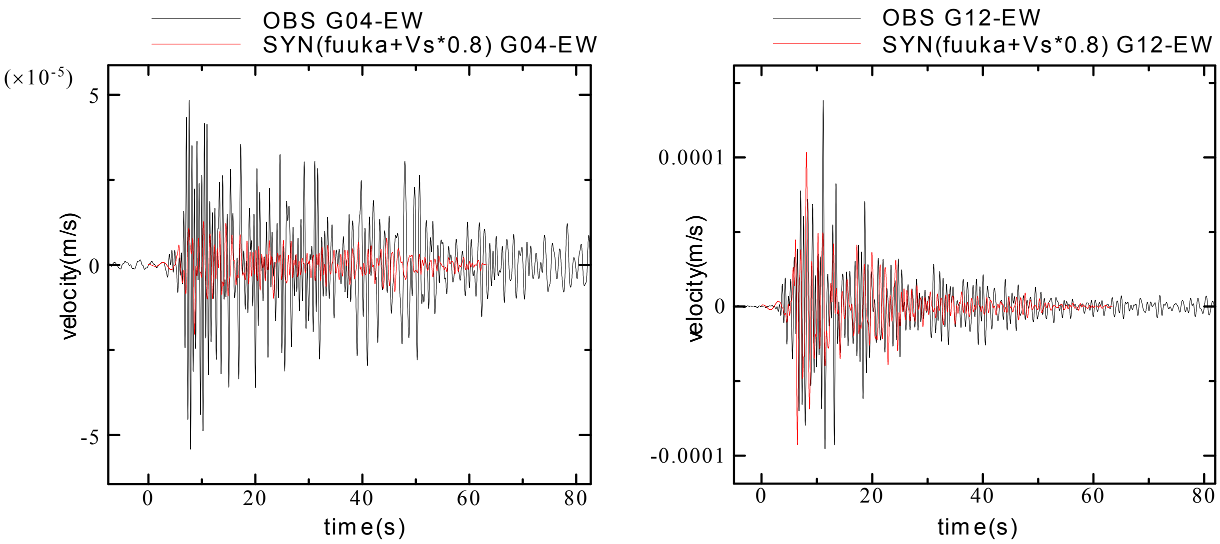
Because amplitudes of velocity waves were not enough in first modeling of Chaljub (2006) even in surrounding rock sites, we performed comparison with the model that considered a weathering layer of thickness 100m with Vs=1.5km/s on top of the Chaljub model. As a result, amplitudes are increased to some extent at rock sites, and durations are lengthened, too, so that we can see a little improvement as seen in Figure 9. However, energy values of simulated motions inside this basin with a weathered layer are still smaller than those of observed motions.

Then we create a model with S-wave velocities inside the basin multiplied by 0.8 times, together with a weathering layer in the surrounding rock, to see the effects of softening the basin. As a result, we found that we have quite a good improvement on duration at most of the sediment sites. However, improvement was not so spectacular for energy values. Besides, for stations located in the northeast area of the Grenoble basin, we cannot reproduce waveforms well because energy and energy duration of synthetics are still much less than those of observations. Velocity waveform comparison can be seen in Figure 10 for two sediment sites, one of which is inside the northeastern area. Apparently the amplitude itself is deficient at stations inside the northeastern area. It is seen that there is less energy in Fourier spectrum of synthetics at almost all stations except for rock sites, especially in the frequency range around 1 Hz.

We should note, however, that the agreement of envelopes is not so bad when we compare RMS envelopes of synthetics with those of observations, although there are large differences between the absolute energy of synthetics and observations. Figure 11 shows the envelope function of synthetics, multiplied by 3.5, and that of the observed record. The matching with observation is remarkable if we apply fixed amplitude compensation. This strongly suggests the existence of amplifier in the northeast area.

As the last investigation, we simulated responses of a model without a basin, that is, a rock only model. As a result, we found a strange phenomenon; in northeast area the energy durations of EW component are getting longer as the location of stations moves from northwest to southeast. This suggests that there is a possibly of long duration in this area in addition to the basin geometry and velocity structure. Note that it is not thought to be a source factor such as directivity because of the positions between stations and the source. Thus it is valuable to consider different possibilities on what is the cause of long duration in the northeast area. At this moment we have to admit that we cannot resolve the mystery yet since we can get only qualitative improvement on energy and energy duration through our parametric studies.

In this study we assume the same thickness ratio in the basin structure throughout the area, however, the simulation studies here shows that it may be necessary to add softer surface layers with smaller Vs only in northeast area. This corresponds to the result estimated by array observation (Tsuno et al., 2007) in CAMPUS station located near the northeast area, in which there is a layer with Vs ~200m/s with the thickness of 25m as shown in Figure 12. From such a result, it seems necessary to review a present structure model mainly in the northeast area of the Grenoble basin for more precise reproduction of observed records.



G04 in the northeast area

G12 in the other area

Figure 10. Comparison between observed and synthetic velocity waveforms.

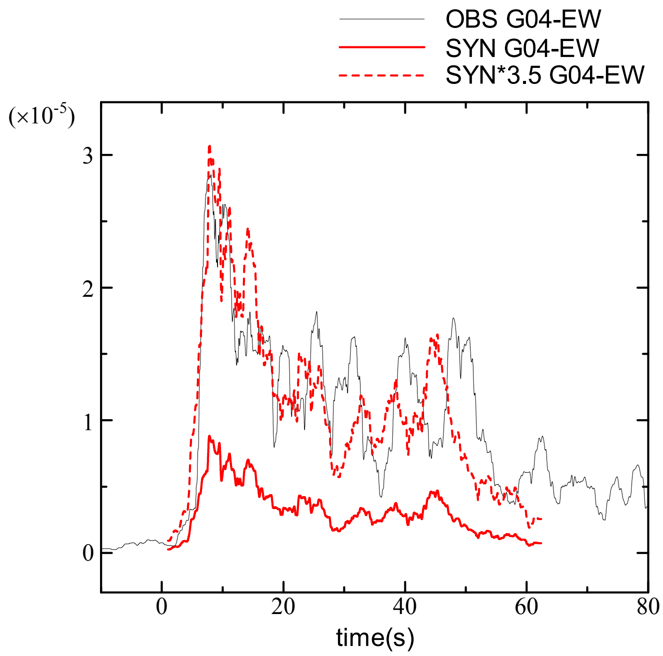


Figure 11. RMS envelope of velocity waveform in the northeast area. Black: observed; red: calculated; red dotted: 3.5 times of calculated

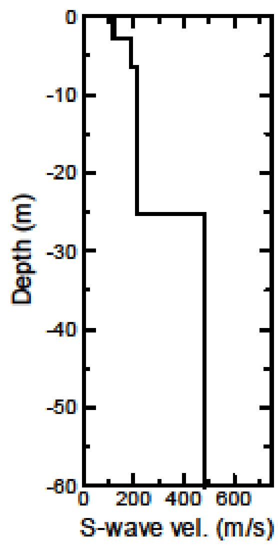


Figure12. Result of array measurement in CAMPUS site close to the northeast area (after Tsuno et al., 2007).

6. CONCLUSIONS

We performed several different types of analyses in terms of energy duration and Arias duration of observed data for two local (d<20 km), small (M2.8, M2.9) events and one regional (d=150 km), larger (M4.4) event. We also conducted 3-D FDM analyses by introducing different medium properties into the reference model of the Grenoble basin proposed before. Major conclusions in this study are as follows:

Ground motions with extraordinarily long duration are observed only in the northeast area of the Grenoble basin and only in one local event, Laffrey2005.

Major frequency bands to contribute to the duration are different for different earthquakes, and it may be due to the magnitude or the distance.

The simulation results were able to reproduce observed energy and energy durations for sites on sedimentary layers except for those in the northeast area of the basin. Despite of the various models used here, we were not able to reproduce long durations and large amplitudes of the stations in the northeast area. We speculate that the observed high amplitudes and long durations may be cause by local, soft sedimentary layers only in that area. Smaller Vs layers estimated by the array observation support this inference.

Thus further investigations on shallow sedimentary layers inside the Grenoble basin will be needed to predict quantitatively responses of the basin based on the 3-D modeling of its velocity structure. However, the matching as seen in Figure 10 at stations outside of the northeast area up to 2 Hz is quite encouraging, although we cannot match each phase of the waveform in such a high frequency range.

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