Grenoble

Seismic hazard and site effect in the Grenoble valley

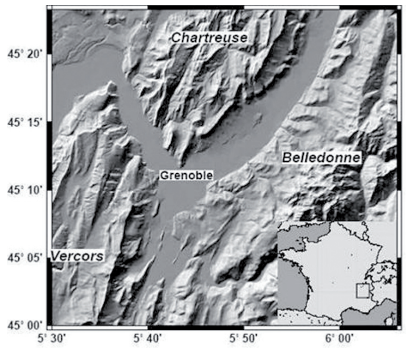

Figure 1: Situation map of the Grenoble area in the French Alps.

The city of Grenoble (SE of France) is located in a 'Y'-shaped embanked alpine valley, surrounded by the Belledonne, Vercors and Chartreuse massifs. The Isère valley (61km long and 5km wide) is a NW-SE structural accident aggravated by glacial and fluviatile erosion.

This area is a seismic region with some historical earthquakes like the 1822 Chautagne earthquake (Mw≈6, I = VII-VIII) or the 1905 Chamonix earthquake (Mw=6, I = VIIVIII). In 1996, a Mw≈5 earthquake occurred in Annecy at about 120km of Grenoble. Despite the large distance, this earthquake has been clearly felt by the Grenoble inhabitants. Indeed, the several hundreds of meters of post-glacial lacustrine sediments which constitute this valley cause important amplification of seismic motion (e.g. Lebrun et al., 2001). Geology and seismicity studies indicate the possibility of earthquakes as large as M5 -5.5 close to the Grenoble area. A right-lateral, strike-slip event is likely to occur on the fault located along the Belledonne massif east of the Grenoble basin (N30°) (Thouvenot et al., 2003).

Instrumentation

Before the Sismovalp project, seven permanent stations of the french accelerometric network (RAP) were already deployed in the Grenoble area (one on the bedrock and six in the basin, including two within a borehole). Thank to these stations records, the amplification caused by the lacustrine layer was observed in the Grenoble valley in a frequency range of 0.3 to 5Hz.

In 2005, 20 temporary broadband stations were deployed inside the basin to characterize ground motion in the valley of Grenoble. Half of the stations were deployed along a 2D profile across the Eastern part of the valley, with the objective of characterizing surface waves diffracted off the valley edges. Thanks to this experiment, the Mw 4.6 Vallorcine earthquake (08/09/2005, about 150km from Grenoble) has produced a unique set of data which is currently analysed. The other half was distributed to cover the central part of the valley in order to characterize, at the kilometrescale, the spatial variability of the amplification and lengthening of duration of ground motion. A permanent borehole station has also been installed at 40 meters depth (Montbonnot borehole). To study in more detail the effects of surface geology on seismic ground motion, microtremor free-field measurements have been performed at 300 points (Guégen et al, 2007).

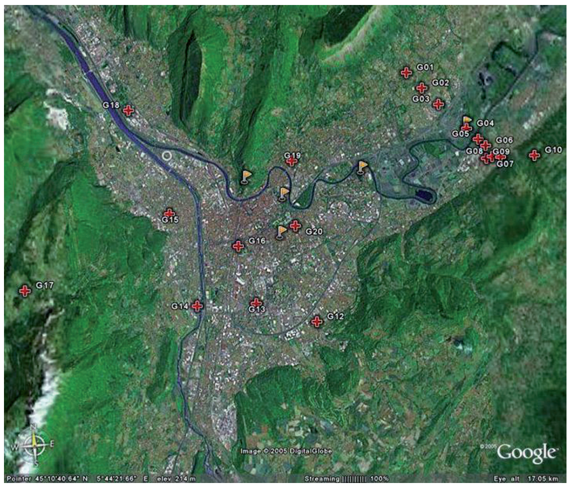

Figure 2: situation of the stations: flags represent the RAP network, whereas the red crosses represent broadband velocimeters deployed temporarily to analyze site effects.

Characteristics of the valley

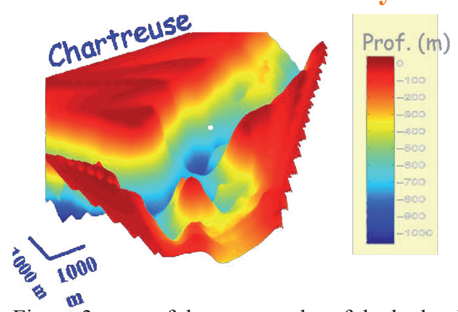

Figure 3: map of the topography of the bedrock

The substratum consists of Jurassic marls and marly limestone. Sedimentary fill is composed of coarse fluvioglacial deposits at the base, overlain by a layer of clays, a layer of sand and gravel, and finally a silt-layer near the surface. Previous geophysical studies (gravimetry, seismic prospecting, borehole measurements) have allowed to constrain a 3D model of the basin: the very dense gravimetric measurements allow obtaining the accurate topography of the bedrock (figure 3). This topography shows the great thickness of sediment (500m in the Gresivaudan, and up to 800m under Grenoble) and their lateral variability, which causes wave trapping. The Vs profiles are also well known using seismic prospection and show the very high contrast between sediments and bedrock (around 3).

Evaluation of the site effect

Valley shape and ground motion resonance

A site effects study was performed using H/V spectral ratios from earthquake data and from ambient noise, as well as standard spectral ratio technique using the reference station located on the edge of the basin. The ambient noise measurements allow us to map the fundamental frequency peak in a frequency range between 0.2 Hz and 10 Hz in the Grenoble basin (Figure 4). Spectral ratio analyses have showed that ground motion amplification occurs mainly in a frequency range between 0.25 Hz and 2 Hz. The resonance frequency around 0.3 Hz is related to the global response of the basin. Higher frequencies amplifications are related to the heterogeneity of superficial layers (Guégen et al, 2007).

Resonance frequencies significantly differ from the 1D local resonance frequencies (overestimation up to 50%). This overestimation is explained by the small aspect ratio of the valley, which causes 2D/3D resonances to occur, which frequencies differ significantly from 1D local resonance frequencies. In order to better characterize these resonances, ambient vibration campaign was carried out involving simultaneous noise recordings at ten stations deployed along three profiles across the northest and northwest branches of the valley. Analysis of the noise spectral amplitudes allows characterizing these 2D/3D resonance patterns (Cornou et al., 2006).

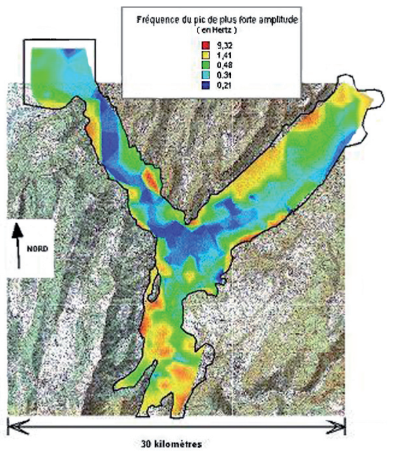

Figure 4: map of the frequency corresponding to the maximum amplitude of H/V spectral ratios in the range 0.2 Hz to 10 Hz.

Ground motion simulations

The propagation of seismic waves has been simulated in our 3D model of the Grenoble valley with the spectral element method (SEM), including the effect of surface topography. The comparison of the SEM synthetics to recordings of local small magnitude earthquakes shows a reasonable agreement for frequencies up to 1 Hz.

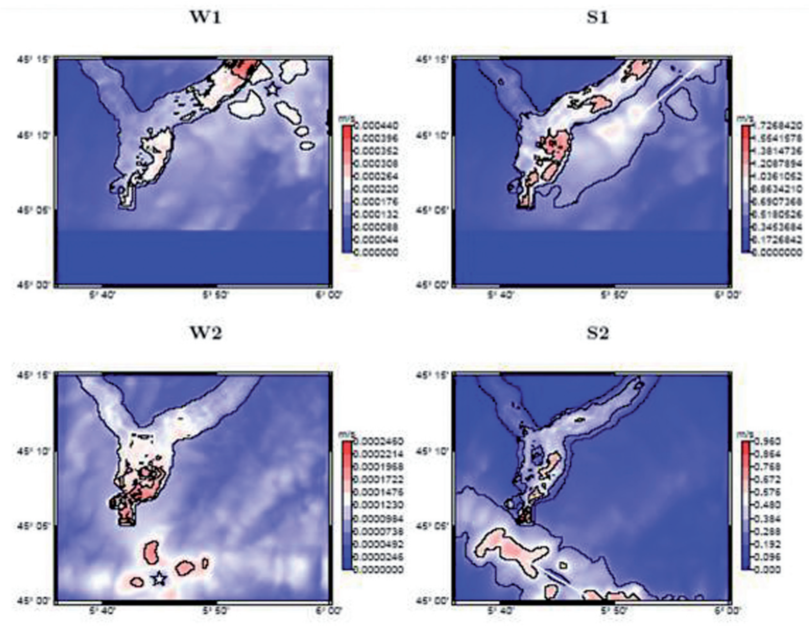

Figure 5: Maps of peak ground velocity computed for four cases: weak motion cases W1 (top left) and W2 (bottom left); strong motion cases S1 (top right) and S2 (bottom right). The `Y'-shaped footprint of the sedimentary filling is indicated by the thick external line

Figure 5 shows the maps of peak ground velocity (PGV) obtained for different events: The two weak motion cases (referred to as W1 and W2) correspond to the ML=2.9 Lancey event of 2003/04/26 (see figure 5) and the ML=2.8 Laffrey event of 2005/10/01, respectively. The strong motion cases S1 and S2 were defined as extrapolations of the weak motion cases W1 and W2 to magnitude 6 events. The simulation shows that most of the amplification occurs in the eastern part of the valley for a seism located on the Belledonne fault. The distribution of PGV is in general similar for weak and strong motion cases, except in the S1 case where source directivity amplifies considerably the S wave impinging the south-eastern part of the valley. At the frequencies considered here and given the simplicity of the velocity model (no lateral variations), the peak values of ground velocity are caused by interferences of surface waves diffracted off valley edges. We found that the effect of surface topography is less important within the valley (40% variations in the peak ground velocity values were obtained) than at rock sites outside the valley where aggravation factors of 2.5 are predicted. Amplification on mountain crests and deamplification in ridges seems to be systematic, whereas seismic motion on slopes is less predictable (Chaljub, 2006).

Comparison with future EC8 building code

Our predictions (Causse et al., 2007) for a site located in the centre of the basin exceed the future European regulation spectra (EC8) for standard to stiff soils (category B or C in EC8 classification. This suggest that European regulations are not suitable for designing structures in alpine valleys and that microzonation studies are needed in such a geological context.

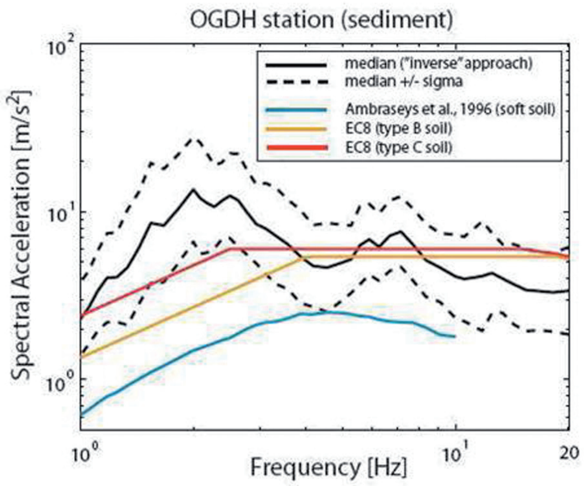

Figure 6: Median spectral acceleration and standard deviation on sediment from the «inverse» approach. Comparison with Ambraseys et al. (1996) equations for soft soils and EC8 (after Causse et al., 2007).

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