Grenoble, Isère river valley (France)

Situation of the valley

The city of Grenoble (SE of France) is located in a 'Y'-shaped embanked alpine valley, surrounded by the Belledonne, Vercors and Chartreuse massifs. This area is a seismic region which some historical earthquakes like the 1822 Chautagne earthquake (Mw≈6, I = VII-VIII) or the 1905 Chamonix earthquake (Mw=6, I = VII-VIII). 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 (Vallon ,1999) which constitute this valley cause important amplification of seismic motion (e.g. Lebrun, 1997; Cotton et al., 1998; Cotton et al., 1999, 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).

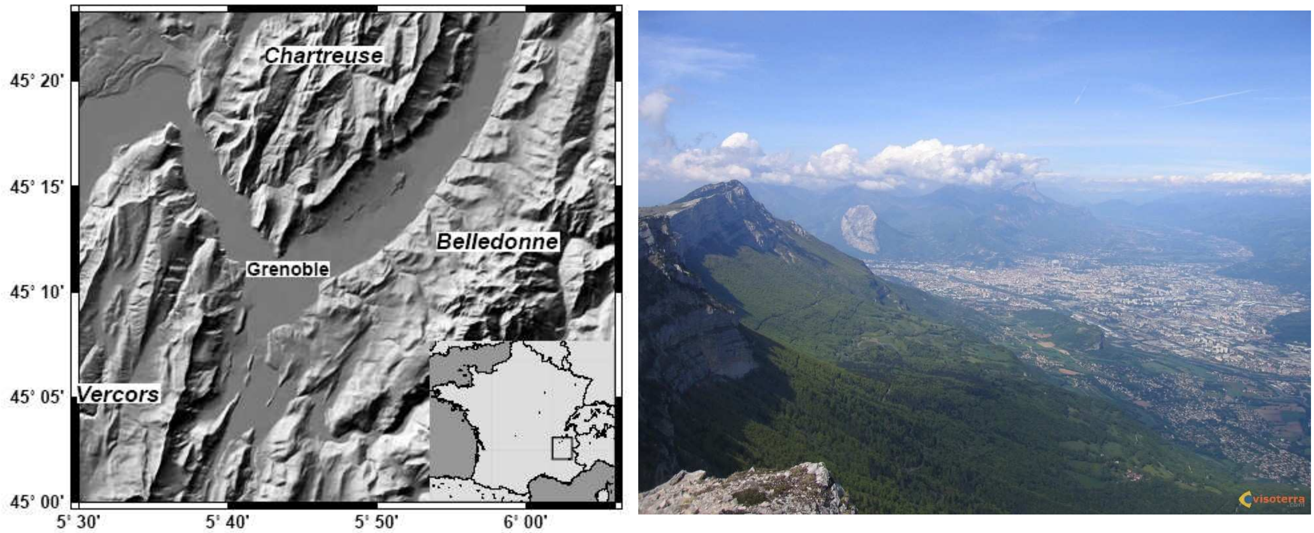

Figure 1: Situation map of the Grenoble area in the French Alps, showing the 'Y'-shaped Grenoble valley surrounded by the Vercors and Chartreuse limestone massifs with maximal elevation of 2000 m and the crystalline Belledonne chain where elevation reaches 3000 m.

The Isère valley (61km long and 5km wide) is a NW-SE structural accident aggravated by glacial and fluviatile erosion. 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.

State of the art of the instrumentation and measurements in the valley at the beginning of the project

Previous geophysical studies (gravimetry, seismic prospecting, borehole measurements) have allowed to constrain a 3D model of the basin. This model allows numerical simulation of ground motion up to 1 Hz.
Ambient noise measurements have also allowed us to obtain Vs profiles. 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 5 Hz.

Instrumentation and measurements realized in the valley during the project

The 8 September 2006, Mw=4.6 Vallorcine earthquake (about 150 km from Grenoble) and its aftershock sequence were recorded with 20 temporary broadband stations 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.

The other half was distributed to cover the central part of the valley in order to characterize, at the kilometre-scale, 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).

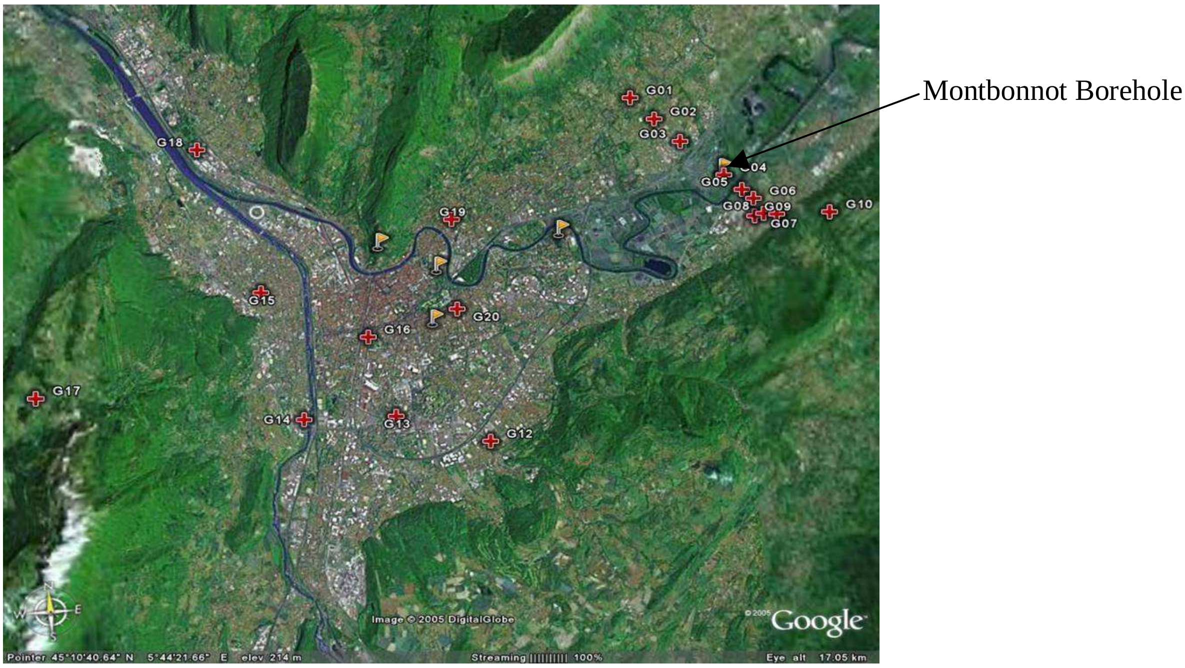

Figure 2 : situation of the stations in the Grenoble valley. Flyers represent the RAP network, whereas the red crosses represent broadband velocimeters deployed temporarily to analyze site effects.

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).

In order to establish the non linearity curves by means of cyclic triaxial tests on undisturbed samples of lacustrine clay, a boring to 48.5 meters with intact core sampling between 40 and 48.5 meters was carried out in the industrial zone near the village of Crolles (NE Grenoble). To predict soil liquefaction of the superficial layers, some in situ tests were performed (CPT, piezocone, seismocone).

Results

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 3). 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)

H/V peak frequencies and shape obtained by both gravimetry and H/V measurements are in good agreement, outlining the reliability of the 3D model. H/V peak 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, we carried out ambient vibration campaign 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).

Moreover, robust site responses relative to an average rock site response have been derived with a new inversion method (Drouet et al., 2005, 2007) for each station located in France allowing us to compare Alpine site affects with site effects observed in other part of France. This study confirms the high level of site amplifications in alpine valleys.

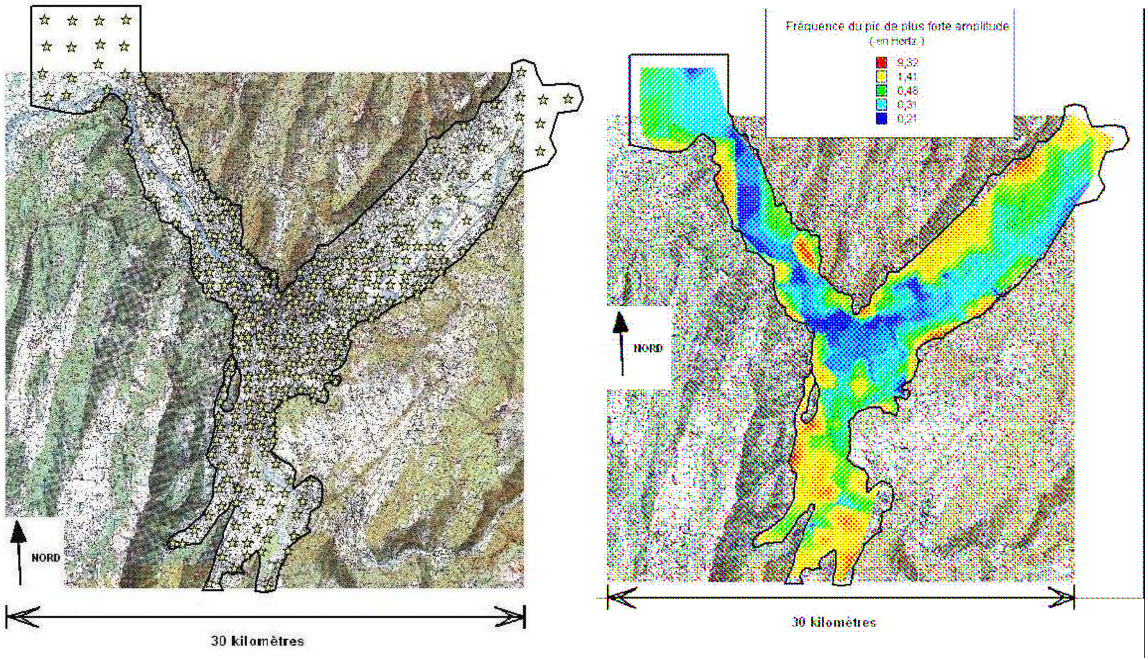

Figure 3: Left: ambient noise measurements (each star represents one measure). Right: map of the frequency corresponding to the maximum amplitude of H/V spectral ratios in the range 0.2 Hz to 10 Hz.

Ground motion simulations

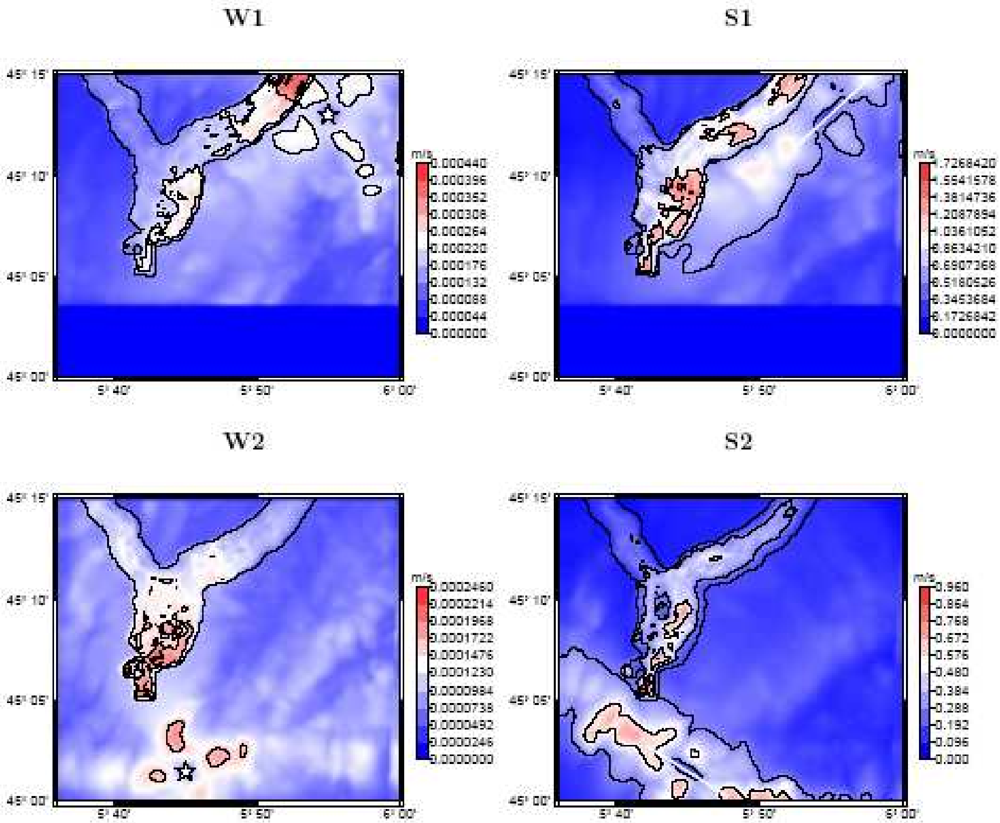

Figure 4: Maps of peak ground velocity computed for the four benchmark cases: weak motion cases W1 (top left) and W2 (bottom left); strong motion cases S1 (top right) and S2 (bottom right). The `Y'-shaped footprint of the sedimentary filling is indicated by the thick external line. Note that all simulations show little amplification in the western branch of the valley and close to the bedrock uplift in the centre of the valley. The high values obtained in the S1 case are caused by a directivity effect.

We simulate the propagation of seismic waves 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 4 shows the maps of peak ground velocity 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 4) 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. 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

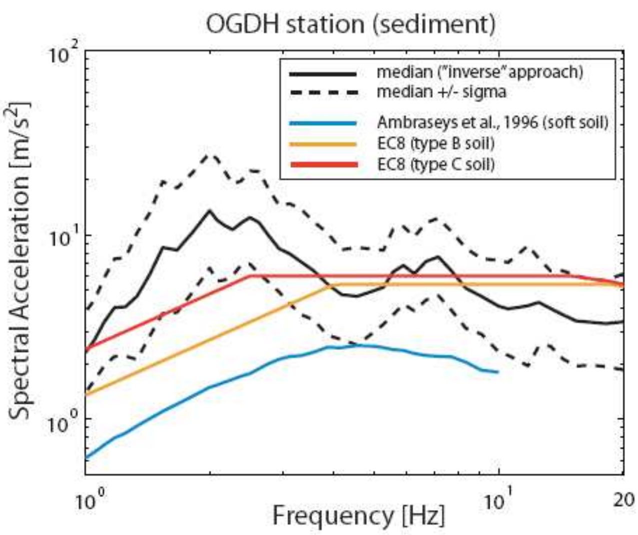

Figure 5: Median spectral acceleration and standard deviation on sediment from the "inverse" approach. Comparison with Ambraseys *et al.* (1996) equations for soft soils and EC8 (after Causse et al., 2007).

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 5).

Contacts with stake holders

The results of the work done in the Grenoble basin were presented in two occasions: the Third International Symposium on the Effects of Surface Geology on Seismic Motion, held in Grenoble from August 30 to September 1, 2006; and on June, 21 2007 in the framework of the reunion about seismic hazard in Alpine valleys.

References presenting the results

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