Bovec basin (Upper Soča valley, Slovenia)

Situation of the valley

The Bovec basin is located in the Upper Soča valley in NW Slovenia, a region undergoing a recent increase in seismic activity. Two strong earthquakes struck the area in 1998 and 2004. The 12 April 1998 earthquake (Mw=5.6) had a maximum intensity of VII-VIII EMS-98 and the 12 July 2004 (Mw=5.2) earthquake VI-VII EMS-98. The epicentral distance to the town of Bovec was 6-7 km. Strong variations in damage to buildings were observed within short distances in the whole Bovec basin. They cannot be explained by changes in the epicentral distance or by changes in the radiation of seismic energy from the source, although the latter can have some influence and needs further attention. The variations in damage can only be attributed in part to differences in building vulnerability, since the building typology is similar throughout the area. Local geological conditions (site effects) therefore played the most important role.

The Bovec basin (6 km long and 2 km wide) developed in the Alpine valley of the Soča river, which is elsewhere very narrow (Figs. 1 and 2). The basement consists of Mesozoic platform carbonates of Upper Triassic and Jurassic age. They are overlain by a succession of deep-water flysch or by marly limestone (scaglia) with intercalated calcarenites, shales, marls and conglomerates of Cretaceous age. Quaternary sediments are represented from bottom to top by partly lithified glaciofluvial sediments, overlain by lacustrine chalk. During the Holocene, the chalk was partly eroded (in some areas totally) and covered by glaciofluvial sand and gravel which are weakly cemented in some parts into conglomerate and by unconsolidated moraine (till).

Figure 1: Bovec basin in the Upper Soca valley

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

Seismic microzonation study of the Bovec basin based on surface geological data and data from shallow geotechnical boreholes (Ribičič et al., 2000) has shown that it is not possible to explain with these data most of the observed variations in the distribution of damage. More promising results have been obtained by combined application of microtremors and 1D modelling of ground motion based on the results of shallow geophysical investigations (Gosar et al., 2001). Some locations of probable soil-structure resonance were identified in this study and large variations in damage to buildings related to the 1998 earthquake were explained by significant variations in ground motion amplification between two different parts of the Bovec basin. One strong motion seismic station (BOVC) was operating in Bovec at the beginning of the project.

Instrumentation and measurements realised in the valleys during the project

The aftershock sequence which followed the 12 July 2004 (Mw=5.2) earthquake was recorded with one permanent (BOVC) and five temporary strong motion instruments (Figs. 2 and 3) deployed by the Environmental Agency of Slovenia, the University of Trieste – DST, the Istituto Nacionale di Geofisica e Vulcanologia (Italy) and Istituto Nacionale di Oceanografia e di Geofisica Sperimentale from Trieste (Italy) in the first three days after the main shock. Five stations were equipped with Kinemetrics Etna accelerographs and Episensor or FBA-23 sensors and one station with a Lennartz 3D 1s seismometer. Eight stronger aftershocks (ML=2.5-3.6) were selected for further analysis. Examples of two aftershock records (ML=2.8-2.9) are shown in Fig. 4. The influence of basin sediments is clearly reflected in the amplitude and duration of the accelerograms.

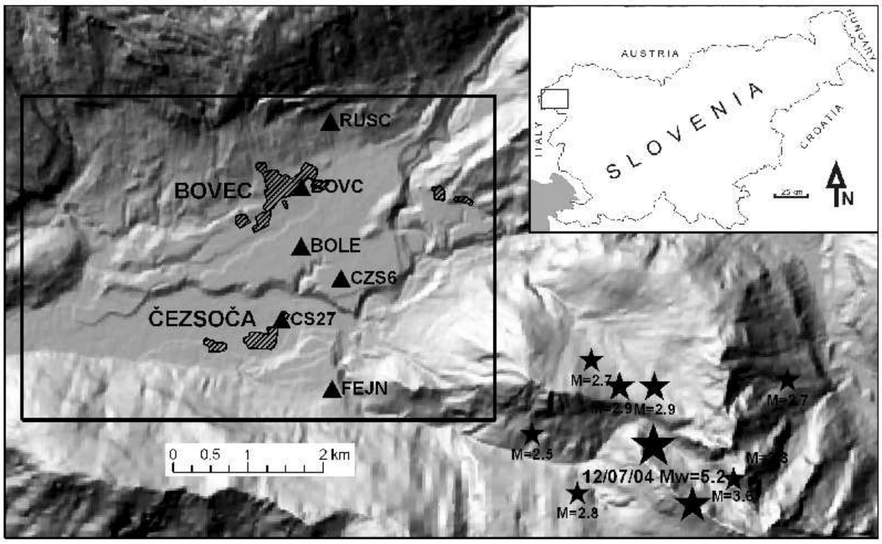

Figure 2: Relief map of the Bovec basin with epicentres of 12 July 2004 earthquake and eight stronger aftershocks. Black triangles are locations of strong motion instruments.

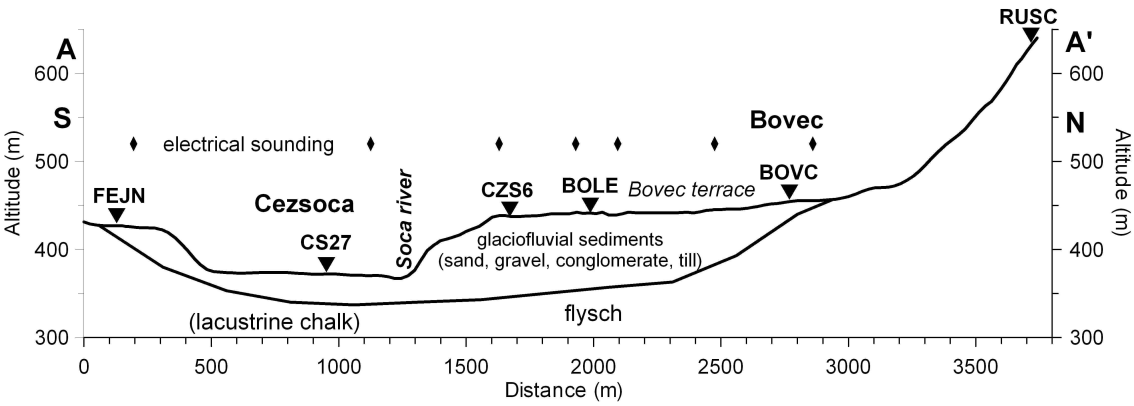

Figure 3: Cross-section of Quaternary sediments in the Bovec basin interpreted from vertical electrical soundings. Black triangles are locations of strong motion instruments.

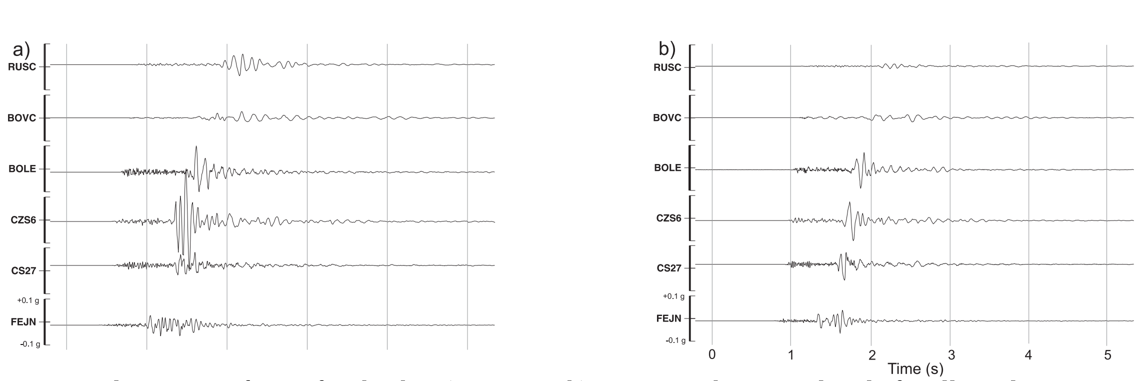

Figure 4: Accelerograms of two aftershocks. a) ML=2.9, b) ML=2.8. The vertical scale for all accelerograms is 0.1 g.

To study in more detail the effects of surface geology on seismic ground motion, we performed microtremor free-field measurements at 124 points in a 200 m dense grid. In addition, 20 buildings were surveyed with the microtremor method to determine the building main frequencies and to identify possible soil-structure resonance.

Results of the work done in the valley

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 (Gosar, 2007b). Spectral ratio analyses showed that ground motion amplification occurs mainly in a frequency range of 5 to 10 Hz, with corresponding amplitudes in the range of 6 to 11. The observed range of amplification cannot be related to the total thickness of Quaternary sediments, which is up to 100 m. The variability in the main peak frequencies and in their amplitudes is therefore explained by the complex geological structure of the basin, filled with heterogeneous glacial and fluvial sediments. Irregular layers of conglomerate within sand/gravel deposits and layers of tillite result in large impedance contrasts at several interfaces within Quaternary sediments. Spectral ratios from earthquake data are therefore quite complex and show a broad range of ground motion amplification. On the other hand, ambient noise data revealed only the first stronger impedance contrast, which is related in the border areas to the flysch bedrock and in the central part of the basin to a shallow layer of conglomerate. Comparison of the two H/V analyses showed that the amplitude obtained from ambient noise data is always lower than the amplitude from earthquake data. The difference can be as much as a factor of two.

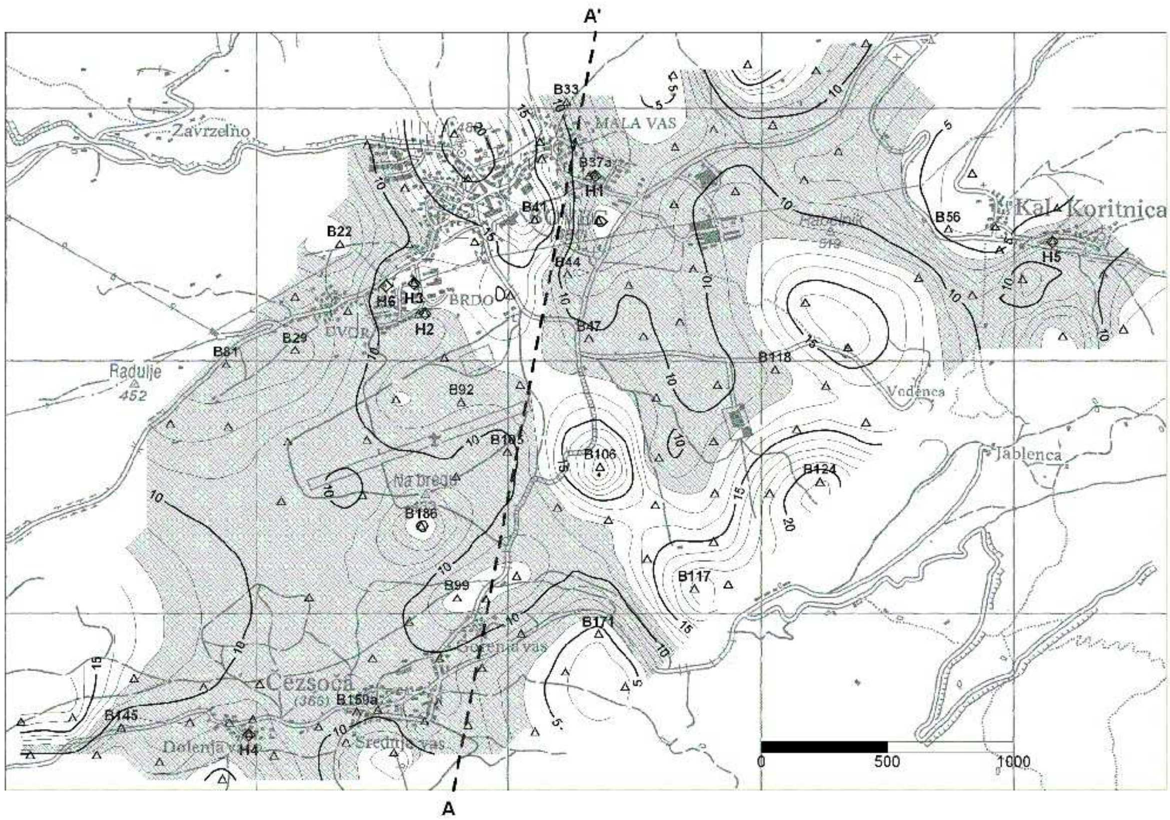

Figure 5 Contour map of the fundamental frequency peak derived from HVSR analysis of microtremor data in the Bovec basin. Frequency range of possible soil-structure resonance (6-12 Hz) is shaded. Triangles indicate points of free-filed measurements; A-A' indicates cross-section shown in Fig. 3.

The microtremor horizontal-to-vertical-spectral ratio (HVRS) investigations showed large variations in the sediments frequency (3-22 Hz), with most of the observed values in the range 6-12 Hz (Fig. 5) (Gosar, 2007a). The observed frequencies cannot be related to the total thickness of Quaternary sediments (sand, gravel), but can be explained by the presence of conglomerate or lithified moraine at shallow depths. The results were compared also with the velocity structure derived from seismic refraction data. Microtremor measurements performed in several two and some three and four storey houses (masonry with RC floors), which prevail in the Bovec basin, have shown that the main building frequencies in the area are in the range 7-11 Hz. This indicates that damage to houses in both earthquakes in some parts of the basin was enhanced by site amplification and soil-structure resonance. This is in agreement with the distribution of damage in both earthquakes. Microtremor investigations have proved an effective tool for assessment of site effects in cases of complex geological structure commonly encountered in young Alpine basins filled with glaciofluvial sediments which are partly cemented. Lithified layers can considerably change the fundamental frequency and, consequently, the site effects.

In addition 2D numerical modelling was applied (Vanini et al., 2006), together with a recently improved technique of 'sub-structuring' (source and site effect) of the problem at study (DRM approach). Numerical modelling, used for computing site effects, is thereby coupled with a method used for source modelling. The combined influence of 1D propagation effects on the dominant frequencies of motion, and of 2D effects on the amplification level and significant frequency band, are highlighted. Ground amplification is high in the frequency range 1-7 Hz. Comparison with Eurocode 8 spectra shows that the latter may not be conservative for periods up to 0.8 s.

Contacts with stake holders

The results of the work done in the Bovec basin were presented to the local authorities and to the office of the Ministry for environment and spatial planning responsible for retrofitting activities in the Bovec region following both (1998 in 2004) damaging earthquakes in the area.

References presenting the results

Vanini, M., Villani, M., Faccioli, E., Gosar, A. 2006: Modelling of strong ground motion of the July 2004, Mw5.2 earthquake in Krn mountains. 3rd symp. on effects of surface geology on seismic motion, Grenoble, Vol. 2, pp. 1-10.

Gosar, A. 2007a: Microtremor HVSR study for assessing site effects in the Bovec basin (NW Slovenia) related to 1998 Mw5.6 and 2004 Mw5.2 earthquakes. Engineering geology (in press).

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