

# RESPONSE SPECTRA FOR THE DEEP SEDIMENT-FILLED RHONE VALLEY IN THE SWISS ALPS

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# **ABSTRACT :**

We present numerical 2D modeling of earthquake ground motion for various profiles across the Rhône Valley in the Swiss Alps and characterize the seismic response in terms of spectral acceleration. Two methods were chosen to compute response spectra in the sedimentary basin: reflecting the epistemic uncertainty of a site response analysis. The first method uses recorded ground motions on rock representing the relevant distancemagnitude range of the probabilistic seismic hazard in the Valais. The signals were used as input in the 2D models of the sites. Even when we applied a generic rock profile to reduce possible effects of soft surface layers, the procedure remained uncertain. It is very likely that site effects affect the frequency content of the input signals used. Moreover, at larger periods the signals lack energy and the resulting response spectra from the limited number of waveforms used do not account for large earthquakes at larger distances. In the second method, the rock hazard spectrum is multiplied with the modeled amplification function at the specific sites. Since we do not know the characteristics of the reference rock condition for the hazard spectrum, it is impossible to estimate such differences in the modeling. At larger periods above 2s, the shape of the hazard spectrum was extrapolated and therefore remains uncertain. We show how the selected method influences the response spectra of the valley sites. Particular attention is paid to how the internal sediment structure and the often weakly constrained Q-factor shape the seismic response. Results obtained for the different profiles are compared with observed earthquake ground motion, and with reference spectra (Swiss building code and Eurocode 8).

**KEYWORDS:** 

seismic ground motion, 1D and 2D amplification, Rhone valley, design spectra, Valais, Switzerland



## 1. EARTHQUAKES IN THE VALAIS (SWITZERLAND)

The Valais is the area of largest seismic hazard in Switzerland (Fäh et al., 2003) and has experienced a magnitude 6 or larger event every 100 years (1524, 1584, 1685, 1755, 1855, 1946), with the last magnitude 6.1 earthquake in 1946 close to Sion and Sierre (Figure 1). This area and in particular the region of Visp hold special interest: on average the Visp region was hit by damaging earthquakes every 40 years (Intensity VI-VIII), with the last in 1960 reaching a macroseismic intensity of VIII. The Visp event of 1855 was the largest in Switzerland for the last 300 years. Besides its seismic activity the test area in the Valais is characterized by several factors adding to the total hazard level: rough topography, unstable and steep slopes, deep sediment-filled valleys, wide glacier- and snow-covered areas. On the one hand, during the Brig event (Mw=6.1) in 1755, the Visp event in 1855 (Mw=6.4) and Sion/Sierre event in 1946 (Mw=6.1) the area experienced great damage from earthquake ground motion and different secondary phenomena such as liquefaction in the Rhone plain, landslide reactivation and extended rock fall.



Figure 1 Large earthquakes in the Valais and the timing of magnitude 6 or larger historical events.

#### 2. GOALS OF THE PROJECT

This study was part of the SISMOVALP Project aiming at the better characterization of the seismic response of sediment-filled valleys in the Alpine Regions. The project included field surveys, updating of the seismic networks, numerical modeling of the seismic response and computation of response spectra. The project was closely related to the SNF project SHAKE-VAL ("Earthquake shaking in Alpine valleys") that was finalized by the end of 2007. The project SISMOVALP allowed the installation of pairs of strong motion instruments in Monthey and Sion, with one station on sediments and one station on bedrock.

Field surveys included noise measurements (H/V and Arrays) to better define the valley geometry and the characteristics of the different types of sediments (Figure 2). A sand/silt layer observed in many places in the Rhone valley is the most critical ground condition in addition to some alluvial cones. Such sites will be the places of severe ground shaking and liquefaction in future earthquakes.



In the case of the Rhône Valley, Frischknecht et al. (2005) recognized strong 2D resonance behavior from numerical simulations. Steimen et al. (2003) and Roten et al. (2006) measured the 2D resonances, including the frequencies of the fundamental mode SV and the fundamental and first higher mode of SH waves. These measurements were performed using ambient noise data recorded along 2D profiles across the valley. The measurements were confirmed by numerical modeling. The noise wavefield is dominated by standing waves at low frequencies (0.25 to 0.50 Hz). The factors influencing the 2D resonance are the shape ratio of the valley and the average impedance contrast between sediments and bedrock. From other investigations, it is known that the seismic response may also be strongly influenced by the source location and characteristics, the composition of the incident wave field and the incidence angle of incoming waves. Earthquake observations and numerical simulations for this Alpine valleys show that the seismic response is dominated by 2D or 3D resonance at low frequencies, while edge-generated surface waves are responsible for significant amplification at higher frequencies (Roten et al., 2008). The expected ground motion is therefore very site-specific.



Figure 2 Sensor positions of the circular (green) and linear arrays (red) in the Rhone valley, and cross-sections for 2D modeling (black lines). Response spectra were computed for sites in the Rhone Valley close to the two profiles at Vetroz and Martigny.

#### 3. FIELD MEASUREMENTS USING AMBIENT VIBRATIONS

During the SISMOVALP project a series of measurements were performed (Figure 2). This included measurements along valley cross-sections in order to determine the 2D fundamental frequencies of resonance of the structure, and small arrays in order to determine the S-wave velocity structure. Typical soil profiles and the variability of the different soil types were defined. The sites of the strong motion stations were also of special interest. A linear array configuration with the sensors aligned on a profile perpendicular to the valley axis was used near Martigny, Saillon, Vetroz, Bramois (red points in Figure 2). From these noise records, site-to-reference spectral ratios were calculated to identify the 2-D resonance frequencies of the deep basin (Roten et al., 2006). At the same sites, large circular arrays (green points in Figure 2) were recorded to derive dispersion curves with the high-resolution frequency wavenumber technique (Ohrnberger, 2004; Wathelet, 2005; Kind et al., 2005).



Both 2-D resonance frequencies and dispersion curves were inverted for shear-wave velocities of the sedimentary fill, using a method developed in the frame of the SHAKE-VAL project (Roten and Fäh, 2007). Figure 3 shows the resulting velocity models and their misfit for the Martigny site. For the models with acceptable misfit,  $v_s$  does not exceed 1200 ms<sup>-1</sup> inside the unconsolidated deposits. A strong velocity contrast can be seen at 180 meters depth, where  $v_s$  increases from 350 to more than 650 ms<sup>-1</sup>, which was also resolved near Saillon and Vetroz. Measurements in the old town of Sion and on the Bramois fan yielded velocities of about 700 ms<sup>-1</sup> close to the surface, which shows that  $V_s$  is lower on the fine lacustrine Rhone sediments than on the coarser material on the alluvial fans.

Table 1 summarizes shear-wave velocities and the uncertainty estimated for the different units of Rhone sediments. At many sites, a very shallow (5 - 10 m), sandy/silty low-velocity layer with shear-wave velocities as low as 100 m/s was resolved. Since such low-velocity sand/silt layers are very important in terms of ground shaking and liquefaction, smaller circular arrays were recorded to define the shear-wave velocity of the shallow Rhone sediments. This low-velocity layer is observed in many places in the Rhone valley, and it is the most critical ground condition, beside some of the alluvial cones.



Figure 3 Martigny site: Shear-wave velocities (bottom left), dispersion curves (bottom right) and different mode 2-D resonance frequencies (top) for the calculated velocity models. Solutions with an acceptable misfit are plotted in dark red.

Depth [m]	Vs	unit
0	100 - 200	uppermost layer
5 - 10	320 - 375	deltaic sediments
65 - 100	385 - 500	lacustrine deposits
175 - 200	500 - 800	glaciolacustrine deposits
350 - 500	700 - 1000	meltout and reworked till
550 - 800	700 - 1000	subglacial deposits

Table 1 Shear-wave velocities assigned to individual layers from results of the array measurements near Martigny, Saillon and Vetroz. The uncertainties reflect the scatter within the models with acceptable misfit and the variability of the velocity at the different sites (Roten and Fäh, 2007).



The findings and conclusions from the field measurements are supported by our historical research performed in the framework of a project related to the analysis of past large earthquakes in Switzerland (SNF project "The history of strong earthquakes in Switzerland"). Figure 4 overviews the reconstructed damage in the village of Visp (Fritsche et al., 2006), a site severely damaged during the 1855 Mw=6.4 earthquake. Also given are the observed secondary phenomena. Due to widespread liquefaction, subsidence and lateral spreading of the sand layer in the undeveloped river plain, the government in 1855 discussed whether further construction should be forbidden. However these issues were forgotten in the decades that followed.

The sites of the strong motion stations were also of special interest in order to explain observed and future ground motions. Small arrays were recorded near different strong motion stations (SMAR, SIOM, SIOO, SIOV). At all soft-sediment sites, a shallow low-velocity layer with shear-wave velocities as low as 100 m/s was resolved. Figure 5 shows inversion results obtained near the station SMAR in Martigny. This layer also explains the large ground motion that was recorded during the September 8, 2005, Valorcine earthquake close to the Swiss border (Figure 6). The horizontal acceleration reached values of more than 10%g due to resonance phenomena in the surface layer at station SMAR.



Figure 4 Damage and secondary effects observed in Visp during the 1855 earthquake (modified from Fritsche et al., 2006).

#### 4. MODELLING

The simulation results have been obtained for vertically incident plane SV-waves using the Direct Boundary Element Method (DBEM) in its frequency formulation. Focus is on the variability of the response along one profile and between different parallel profiles. This variability is analyzed with respect to the changing bedrock relief and the local characteristics of the sediments. In this regard, particular attention was paid to the sediment structure and the effect of damping on the seismic response of the valley. The results are presented in terms of response spectra of spectral acceleration computed using two different methods (related to the type of bedrock spectrum). The full result of this study is described in Havenith et al. (2008).

Simulation results of the seismic response of the Rhône valley were studied along three different 2D profiles, using 1D and 2D amplification functions along these profiles. The sites in the valley can be characterized as soils of class C according to Eurocode 8, with vs ranging from 300 to 500 m/s on the surface, increasing at depth to 800 to 1200 m/s. Locally, these sediments are covered with a sand-layer corresponding to soil class D with vs in the range 100 - 150 m/s at the surface.





Figure 5 Shear-wave velocities for the shallow structure obtained from array measurements near the strongmotion station SMAR.



Figure 6. Ground motion recorded during the September 8, 2005, Valorcine earthquake at strong-motion station SMAR.

Two methods were applied to compute the local site-specific response spectra. Method 1 is generally used in engineering seismology. Nine selected accelerograms are used as incident waves into the models, and the waveforms are used to compute the response spectra in the 2D models. The recorded accelerograms are recordings on rock representing the relevant distance-magnitude range of the probabilistic seismic hazard in the Valais. In Method 2 the hazard rock-spectrum (with 10% probability of exceedance in 50 years) is multiplied with the response amplification function for the site of interest. Results are shown Figures 7 and 8. The differences related to the method are considerable (Figure 7). The seismograms used in Method 1 have almost no energy at larger period and the values of the response spectra are very low. The limited number of waveforms used do not account for large earthquakes at larger distances. In general for soil class C and Method 1 the values of the response spectra.



For Method 1 the resulting spectra are better represented by a type 1 spectrum. Since we do not know the characteristics of the reference rock condition for the hazard spectrum, it is impossible to estimate the uncertainty of Method 2. At larger periods above 2s, the shape of the hazard spectrum was extrapolated and therefore remains uncertain.

For soil class D the values obtained with method 1 and 2 are larger then both EC-type spectra (Figure 8), especially for Method 1. However, the values of Method 1 and 2 are upper bounds due to the fact that nonlinear behavior of the soils was neglected in the modeling. Generally the type 1 spectrum used in the Swiss building code is more conservative over a larger period range and therefore is more adequate for the Valais situation.



Figure 7 Typical spectra for one cross-section using the two methods: Method 1(left) and Method 2 (right) for soil type C, compared to EC8 type 1 and type 2 design spectra. The zones are defined according to the distance to the valley border (modified from Havenith et al., 2008).



Figure 8 Typical spectra for a cross-section through the Rhone valley for soil class C (left) and soil class D (right), compared to EC8 type 1 and type 2 design spectra. The zones are defined according to the distance to the valley border (modified from Havenith et al., 2008).



#### REFERENCES

- Fäh, D., Giardini, D. et al. (2003). Earthquake Catalogue Of Switzerland (ECOS) and the related Macroseismic Database . *Eclogae geol. Helv*, **96**, 219-236.
- Fäh, D., Stamm, G. & Havenith, H.-B. (2008). Analysis of three-component ambient vibration array measurements. *Geophysical J. Int.*, **172**, 199-213.
- Frischknecht, C. Rosset; P. and Wagner, J.J. (2005). Toward seismic microzonation-2D modeling and ambient seismic noise measurements: the case of an embanked, deep Alpine Valley. *Earthquake Spectra*, **21**, 635–651.
- Fritsche, S., Fäh, D., Gisler, M. and Giardini, D. (2006). Reconstructing the damage field of the 1855 earthquake in Switzerland: historical investigations on a well-documented event. *Geophys. J. Int.*, **166**, 719–731.
- Fritsche, S. and Fäh, D. (2008). The 1946 Magnitude 6.1 Earthquake in the Valais: Site-Effects as Contributor to the Damage. *Eclogae Geol. Helv.*, submitted.
- Gisler, M., Fäh, D. and Deichmann, N. (2004). The Valais earthquake of December 9, 1755. *Eclogae Geol. Helv.*, **97**, 411-422.
- Havenith, H.B., F\u00e4h, D., Alvarez-Rubio, S. and Roten, D., (2008). Response spectra for the deep sedimentfilled Rh\u00f5ne Valley in the Swiss Alps. *Soil Dynamics and Earthquake Engineering*, doi:10.1016/j.soildyn.2008.01.016, in press.
- Kind, F., Fäh, D., P., Giardini, D. (2005). Array measurements of S-wave velocities from ambient vibrations. *Geophysical J. Int.*, **160**, 114-126.
- Ohrnberger, M. (2004). User manual for software package CAP a continuous array processing toolkit for ambient vibration array analysis. SESAME report D18.06, 83pp (<u>http://sesamefp5.obs.ujf-grenoble.fr</u>).
- Steimen S., D. Fäh, F. Kind, C. Schmid and Giardini, D. (2003). Identifying 2-D Resonance in Microtremor Wave Fields, Bull. *Seism. Soc. Am.*, **93**, 583 599.
- Roten, D., Fäh, D., Cornou, C. and Giardini, D. (2006). 2D resonances in Alpine valleys identified from ambient vibration wavefields. *Geophys. J. Int.*, **165**, 889-905.
- Roten, D. and Fäh, D. (2007). A combined inversion of Rayleigh wave dispersion and 2D resonance frequencies. *Geophys. J. Int.*, **168**, 1261–1275.
- Roten, D., Fäh, D., Olsen, K.B and Giardini, D. (2008). A comparison of observed and simulated site response in the Rhone valley. *Geophys. J. Int.*, **173**, 958-978.
- Wathelet, M. (2005). Array recordings of ambient vibrations: surface-wave inversion. Liège University (Belgium), 177 pages.