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MICROZONATION OF THE CITY OF VISP (SWITZERLAND) USING A 2D EQUIVALENT LINEAR APPROACH

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ABSTRACT

The city of Visp is located in the upper Rhone river valley in Switzerland. It is a typical alpine 2D-valley configuration, where 2D site effects are expected. In the framework of the seismic microzonation of this area, the two-dimensional response of the valley to SH waves is calculated by the discrete wave-number method proposed by Aki and Larner (Aki and Larner, 1970). To overcome the frequency upper bound limitation, the Aki and Larner's method is combined with a one-dimensional computation using a classical multi-layer method (Aki and Richards, 1980). We use an original version of the method to assess the two-dimensional non-linear response of alluvial basins. The so-called "Aki-Larner extended method" is associated to an iterative algorithm, as proposed by Seed and Idriss (1969) which accounts for the modulus and damping degradation using a linear visco-elastic model. A bedrock and S-wave velocity profile is determined through the city of Visp and computations are carried out, using the above described 2D approach, for different points along the profile. Results are given in terms of amplification functions (ratio of the 5% damping response spectra at the surface deposits and at the hypothetical outcropping hard rock). Based on these results and the 2D geological characterisation of the valley, zones of similar site response are determined, and associated design response spectra are given, to be used by engineers instead of the average code spectra. The final microzonation map gathers these information. The results of this study are daily used now, as is has become mandatory to use the site specific spectra instead of the building code average spectra.

Keywords: site effects, 2D simulation, equivalent linear, microzonation

INTRODUCTION

The Swiss Rhone river valley in Valais region is characterised by a typical 2D alpine valley configuration (Lacave and Lemeille, 2006). For this reason, the average design spectra proposed in the seismic code are not sufficient to account for specific 2D amplification effects expected in this region. The city of Visp, located in the upper valley, is furthermore characterised by the presence of a large chemical plant, built in the middle of the valley. In 1855, a magnitude 6.4 earthquake hit Visp, leading to intensity VIII. But at that time, the village was built only on the lateral slope, the valley itself was only used for agriculture, because of the frequent Rhone river floods. The same earthquake today could lead to considerable damages due to a complete expansion of the city and industry on the central valley deposits. Furthermore, the valley is partly filled with thin soft deposits (silts and fine sands) that are susceptible to lead to non linear effects. Liquefaction traces have already been observed in similar places in the upper Rhone valley, during historical earthquakes. For this reason, not only the 2D behaviour but also the non linear behaviour have to be accounted for in this area. This is why a spectral seismic microzonation study was conducted in the Visp area.

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The two-dimensional response of the valley to SH waves is calculated by the discrete wave-number method proposed by Aki and Larner (Aki and Larner, 1970). To overcome the frequency upper bound limitation, the Aki and Larner's method is combined with a one-dimensional computation using a classical multi-layer method (Aki and Richards, 1980). We use an original version of the method to assess the two-dimensional non-linear response of alluvial basins. The so-called "Aki-Larner extended method" is associated to an iterative algorithm, as proposed by Seed and Idriss (1969) which accounts for the modulus and damping degradation using a linear visco-elastic model.

A bedrock and S-wave velocity profile is estimated through the city of Visp and computations are carried out, using the above described 2D approach, for different points along the profile. As they are addressed to the assessment and design of structures by engineers in the area of Visp, results are given in terms of amplification functions (ratio of the 5% damping response spectra at the surface deposits and at the hypothetical outcropping hard rock). Based on these results and the 2D geological characterisation of the valley, zones of similar site response are determined, and associated design response spectra are given, to be used by engineers instead of the average code spectra. The final microzonation map gathers these information. The present paper does not enter into details concerning all the geological and geotechnical aspects of the study. It focuses only on the seismological aspects, especially the site effects estimation.

METHODOLOGY

The code that is used in this study (especially the equivalent linear module) was developed in the framework of the SISMOVALP European project. More details on the code development and validation can be found in Lacave and Hollender (2006).

The extended Aki-Larner model

The computation of the two-dimensional response of alluvial basins is based on the discrete wavenumber method proposed by Aki and Larner (1970). The basis of this method lies on the transposition of the direct problem in space and time domain to the horizontal wavenumber and frequency domain, achieved by a double Fourier transform. To solve the problem numerically, a discretization in both space and time, and thus in wavenumber and frequency, is operated.

Some of the simplifying hypotheses on which this method is based impose a frequency limitation which is approximately in the range between $4*f_0$ and $8*f_0$, f_0 being the resonance frequency of the considered valley. To overcome this frequency limitation, the computation is combined with a classical 1D computation, for frequencies higher than $8*f_0$. Between $4*f_0$ and $8*f_0$, an hybrid solution is linearly interpolated between the 1D and the 2D solutions, as shown on Figure 1.

The equivalent linear model

Since an equivalent linear model accounts for the soil non-linear behaviour, it can be easily introduced in the linear method of Aki and Larner. First proposed by Seed and Idriss (1969), the original equivalent linear method states the modulus and damping degradation in the soil submitted to large strains can be modelled by the response of a linear visco-elastic model. The equivalence between linear and non-linear behaviour is ensured in terms of energy dissipation, represented by the internal area of the hysteresis loop in the stress-strain plane. As a matter of fact, an ellipse area in the stress-strain plane can represent the energy dissipated by the linear visco-elastic model, equal to that of a simple resonating oscillator. Therefore, the energy dissipated by the non-linear material is adequately approximated by the linear model by fitting the ellipse area (equivalent linear) to the area of the hysteresis loop (non-linear).

This is practically achieved by fitting the modulus and damping of the linear visco-elastic model to the effective modulus and damping of the non-linear material under loading. Experimental modulus and damping degradation curves obtained by laboratory tests generally give these effective values. In Seed and Idriss' visco-elastic model, modulus and damping values are computed from these degradation curves by an iterative algorithm. At each iteration, the effective strain is determined. This is done until a convergence limit is reached, between the effective strain at two consecutive iterations. Seed and Idriss' equivalent linear model, widely used in the well-known 1D SHAKE program (Schnabel et al., 1972), was implemented in the extended Aki and Larner method. In the 2D computation, it is assumed that the shear modulus and damping are constant inside each layer, with the strain amplitude being variable (2D computation). In the 2D equivalent linear frame, the mean strain amplitude, computed at several points across the valley within each layer, is used to compute the new shear modulus and damping at each iteration step.

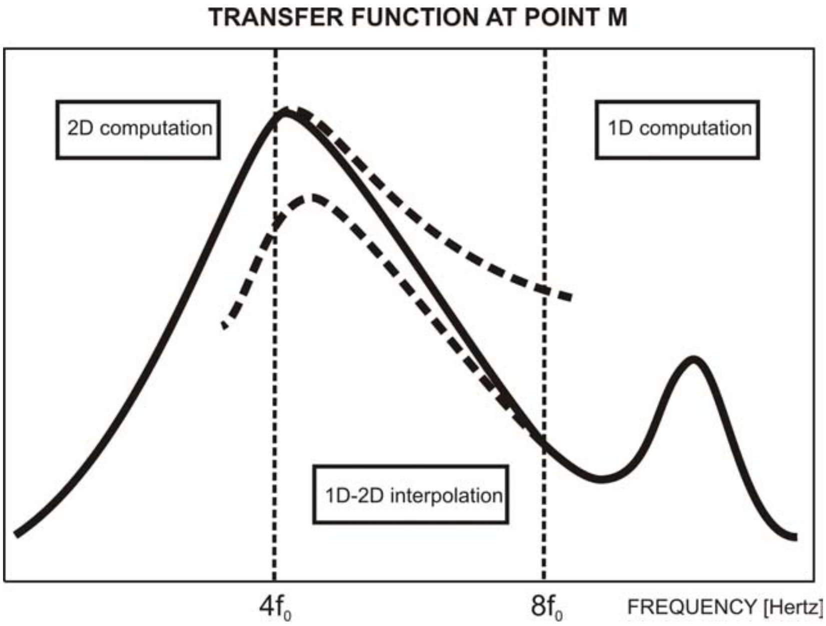

Figure 1. Approximation of the 2D valley response by the extended Aki and Larner's method

REGIONAL HAZARD AND INPUT MOTION

Regional hazard on rock

The Swiss Seismological Service has re-evaluated the seismic hazard for Switzerland (SED, 2004). For any point in Switzerland, the values of spectral acceleration are available for five periods between 0.1 and 2 s (shown by the black diamonds in Figure 2). These values are valid for a "hard rock" type with Vs around 1500 m/s. In analogy with what was determined for the new Swiss building code SIA 261 (Norme SIA 261, 2003), we propose to use, for the "hard rock" with Vs = 1500 m/s, a spectrum with the class A shape and the following design horizontal spectral acceleration value, a_0 :

$$a_0 = \frac{S_a + S'_a}{2} \cdot \frac{1}{2.5} \qquad (1)$$

where S_a and S'_a are the spectral acceleration values for "hard rock" at 5 and 10 Hz respectively. In the case of the Visp area, a_0 = 0.68 m/s^2. The corresponding "rock input spectrum", shown in Figure 2 (black line), is valid for the motion at an hypothetical outcropping hard rock.

Selection of input motions

For site effect computations, a set of five acceleration time histories was selected, that all together cover the input rock spectrum. These accelerograms are either found in the European Strong Motion Database (Ambraseys et al., 2001), or they are semi-artifical accelerograms, created using the Sabetta and Pugliese (1996) program. The characteristics of the selected accelerograms are given in Table 1. It is reminded here that Visp was hit by a magnitude 6.4 earthquake, at about 10 km, in 1855.

The response spectra of the selected input motions, for 5% of critical damping, are shown on Figure 2, in comparison with the rock input spectrum (black). The final surface spectra will be obtained by multiplying the computed amplification functions (ratio of the response spectra at the surface deposits and at the hypothetical outcropping hard rock) by the spectrum valid for "hard rock" (black curve on Figure 2). For this reason, it doesn't matter if the individual input signal spectra are not exactly following the "hard rock" regional hazard spectrum.

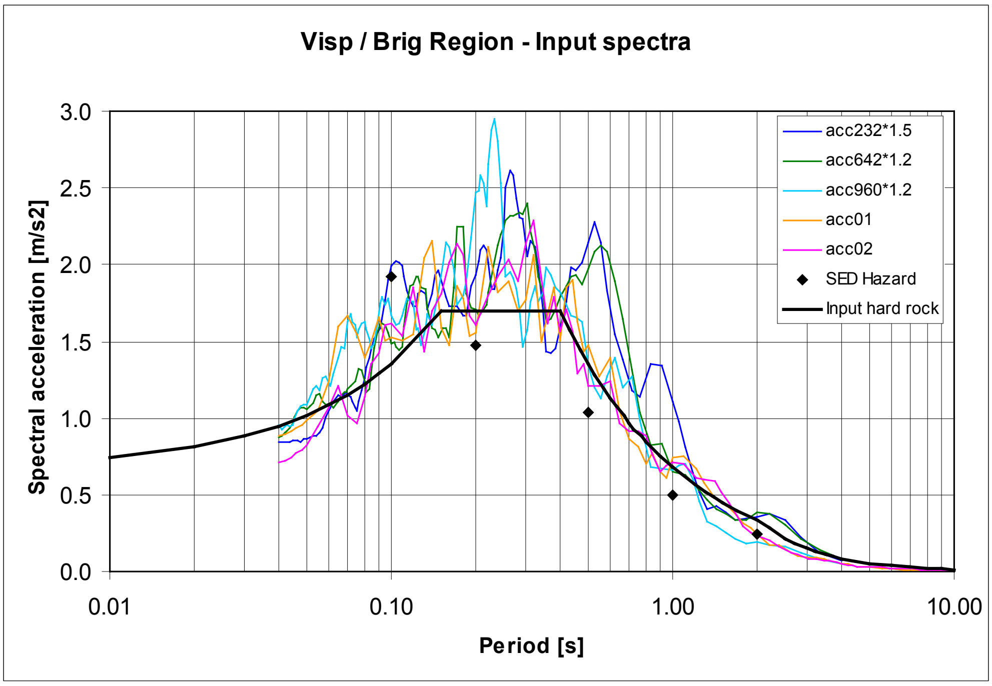

Figure 2. Hard rock regional hazard values (black diamonds) and associated hard rock hazard spectrum (black curve). Coloured curves are the response spectra of the selected input motions.

Table 1. Characteristics of the input motions

Name	Earthquake	Country	Date	M_S	Epicentral distance [km]
acc232	Montenegro	Yugoslavia	05/24/79	6,3	21
acc642	Umbro-Marchigiana	Italy	10/14/97	5,6	23
acc960	Sicilia-Orientale	Italy	12/13/90	5,2	75
acc01	Semi-artificial Sabetta & Pugliese			6,5	50
acc02	Semi-artificial Sabetta & Pugliese			6,5	50

VALLEY AND DEPOSIT PROPERTIES

Bedrock profile

A bedrock profile was drawn across the valley, through the city of Visp, based on geological knowledge. In this part of the Valais region, the valley is about 2 km wide, for a maximum depth of 225 m. The valley is filled with lacustrine, fluvial and morainic deposits, overlaying a granite – gneiss and limestone bedrock (depending on the position along the profile). The sedimentary deposits are made of fine silty sands and gravels. Figure 3 shows the shape of the valley profile. Several points were selected, were the surface motion is calculated using the 2D site effect numerical simulation.

Determination of the S-wave velocity profile

Some measurements of the ambient vibrations have been conducted on the whole Visp area, at 80 points. This made it possible to draw a resonance frequency map of the area.

Using available geotechnical and geological information, especially SPT values when possible, a best estimate S-wave velocity profile has been defined for the centre of the valley in Visp, as the structure is an horizontally homogeneous layered profile. Then, a 2D computation has been conducted for very weak motion, and the natural frequency of the obtained transfer function has been compared to the measured value at the centre of the profile. Finally, the Vs-profile has been adjusted so that the computed resonance frequency matches the measured one. Table 2 shows the obtained velocity profile. The adjustment has been made on the velocity values rather than on the bedrock depth, as the uncertainty is higher on the determination of the velocities than on the bedrock depth in Valais area, where good quality geological data are available (CRSFA, 1991).

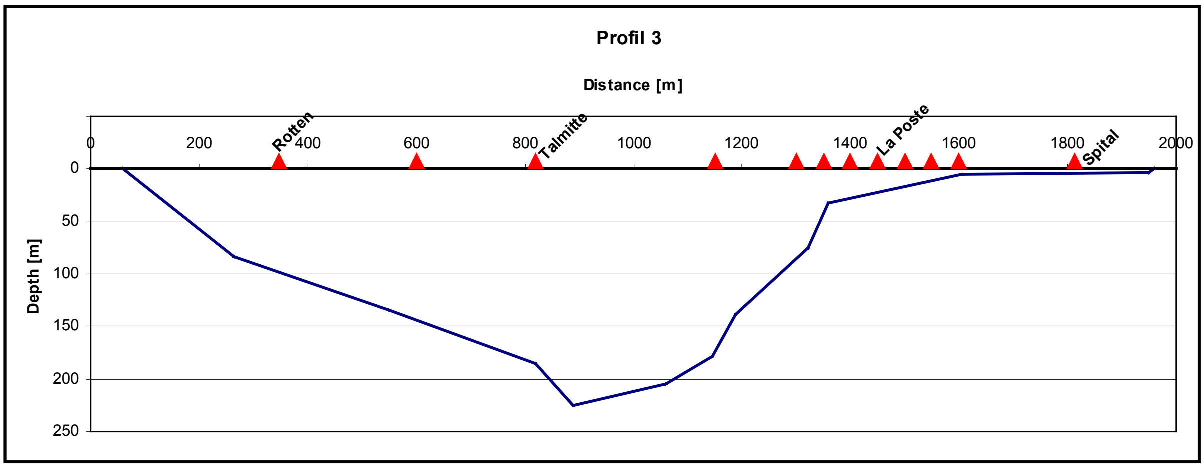

Figure 3. Bedrock profile across the Rhone valley at Visp

Table 2. S-wave velocity profile in the centre of the valley.

Geological formation	Depth of upper interface [m]	Estimated S-wave velocity [m/s]	Adjusted S-Wave velocity [m/s]	Density [t/m^3]
Upper silts and fine sands	0	243	290	1.7
	4	286	340	2.0
Upper Rhone terrace	9	412	490	1.85
Lower silts and fine sands	18	444	530	2.1
Lower Rhone terrace	22	539	650	2.1
	45	641	770	2.15
Sand and gravel deposits	70	800	960	2.15
	100	900	1080	2.15
	130	1000	1200	2.15
Moraine	160	1100	1320	2.2
	180	1200	1440	2.2
	210	1200	1450	2.2
Granite – Gneiss / Marl – Limestone	225	2500	2500	2.65

Equivalent linear behaviour of material

The material curves for the account of the equivalent linear behaviour have been determined using typical curves for the same type of deposits. The curves shown in Figures 4 and 5 correspond to the mean curve between the one from Seed and Idriss (1970) and the one from Ishibashi and Zang (1993) for a plasticity index Ip = 0. As the curves from Ishibashi and Zang (1993) are dependent on the vertical effective stress, they are dependent on the depth.

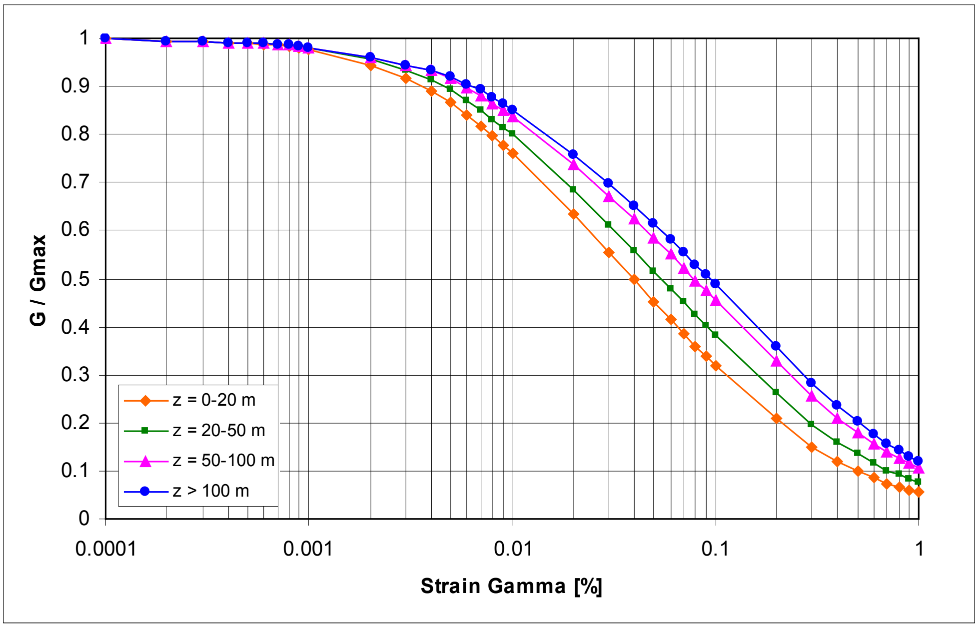

Figure 4. Shear modulus as a function of strain

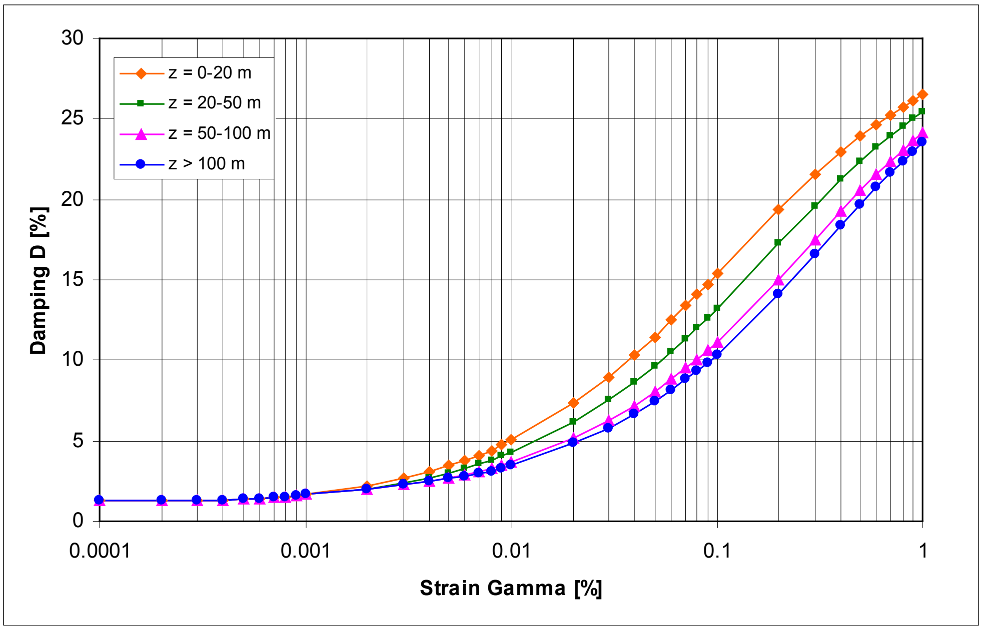

Figure 5. Damping as a function of strain

2D SITE EFFECT COMPUTATIONS

Procedure

The 2D response of the valley is computed for the five input time histories, using the 2D equivalent linear Aki-Larner code. The following procedure is adopted :

- Computation of the surface response at several receivers along the profile, for each input motion,
- Computation of the associated response spectra,
- Computation of the amplification functions : ratio between the surface response spectrum and the input motion response spectrum,
- Computation of the resulting site response spectrum : multiplication of the amplification function by the regional hard rock hazard spectrum.

Furthermore, using the same procedure, a sensitivity study is conducted in order to account for the uncertainties linked to the S-wave velocity estimation and to the input motion characteristics. For this purpose, the following is done :

- The input incidence angle is varied as to be vertical (0°), as well as oblique with values of -30° and +30°.
- The S-wave velocity profile is varied by multiplying the values by a factor of 1.4 and dividing them by a factor of 1.4 (corresponding to a factor of 2 in the shear modulus).

Amplification functions and resulting response spectra

Figure 6 shows, as an example, the amplification functions obtained for the five input motions, at the valley centre, for the mean Vs-profile and a vertical incidence.

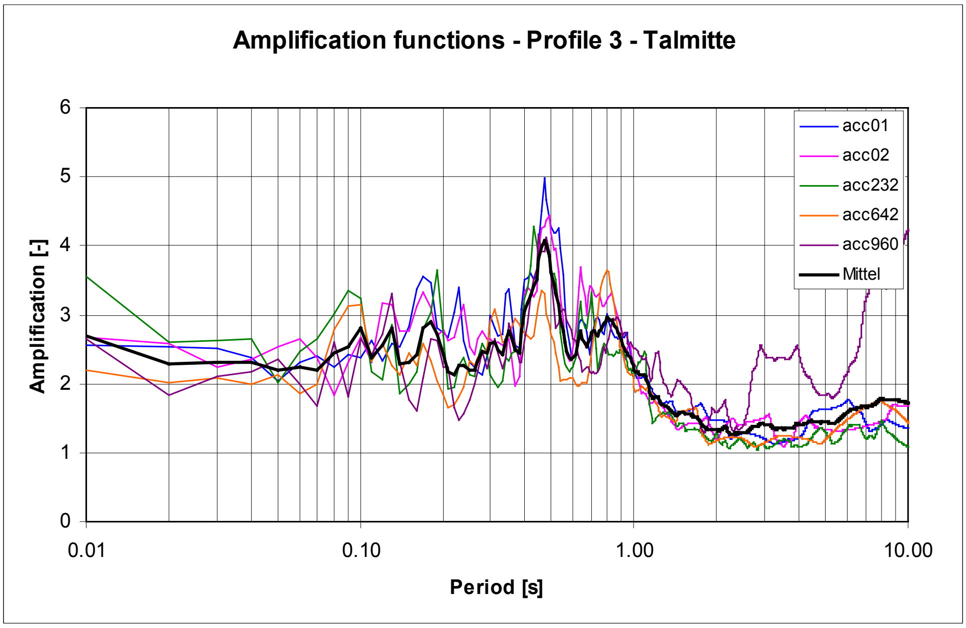

Figure 6. Amplification functions obtained for the five input motions in the centre of the valley

Figure 7 shows, for another location, the influence of the uncertainty on the S-wave profile on the resulting response spectra. Final spectra are chosen accounting for this strong uncertainty on the S-wave velocity profile.

Figure 8 shows the variation on the response spectra, at one point located on the edge of the basin, for different incidence angles. The incidence angle has a particularly strong influence on this side of the basin, characterised by a bevel-edged shape (see Figure 3).

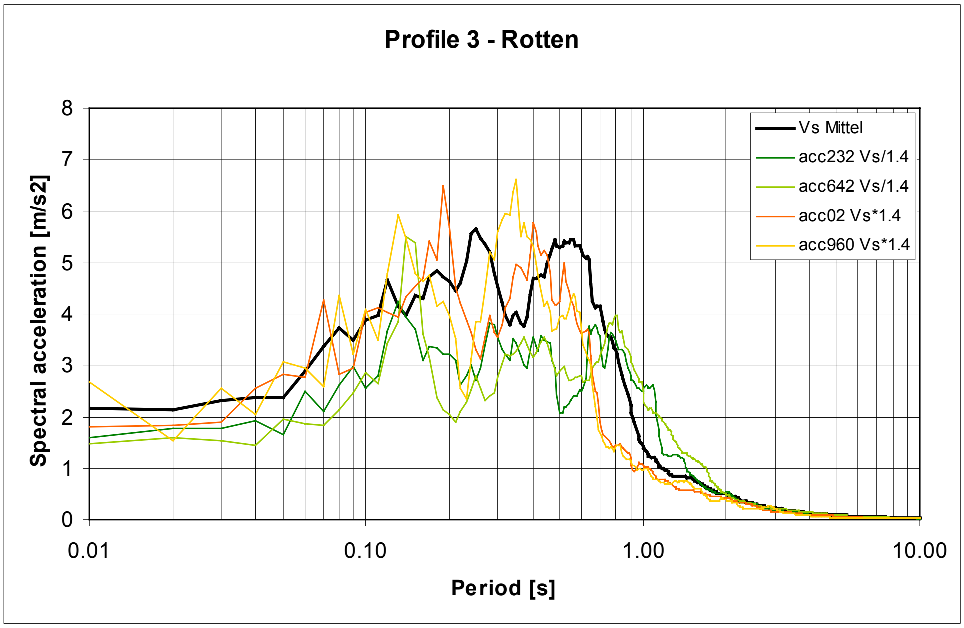

Figure 7. Response spectra obtained with the mean (black curve) and varied velocity profiles

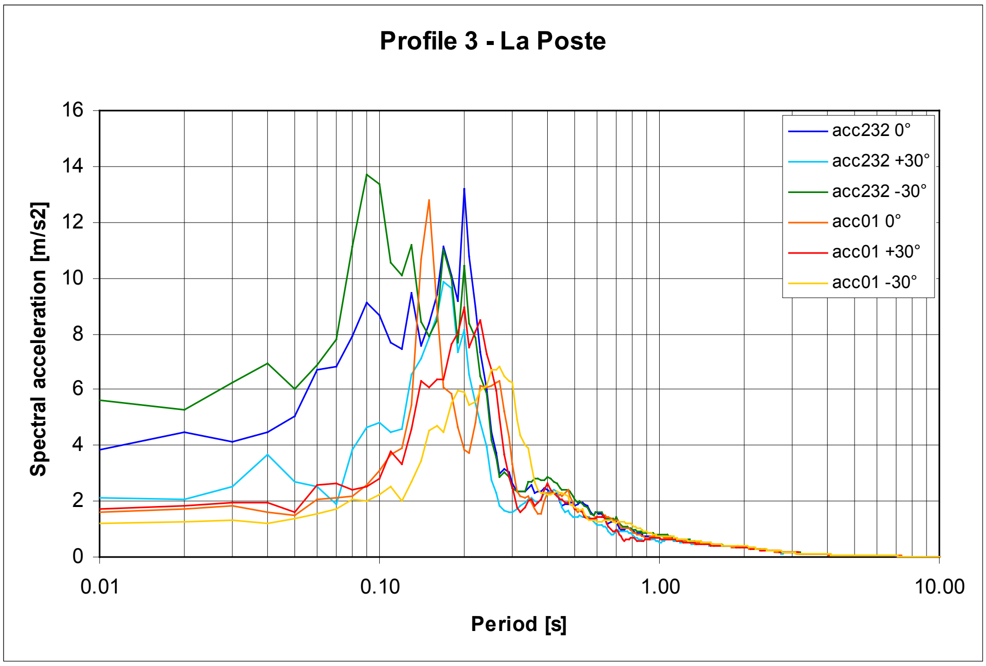

Figure 8. Response spectra obtained for different incidence angles, at point "La Poste" located on the edge of the basin

A strong "high frequency" amplification was obtained for the point located at the edge of the valley, called "La Poste" on the profile of Figure 3. In order to better constrain the lateral extension of this phenomenon, the response spectra have been computed for a dense series of points around "La Poste".

Figure 9 shows the resulting response spectra, exhibiting a strong basin edge effect on this side of the valley.

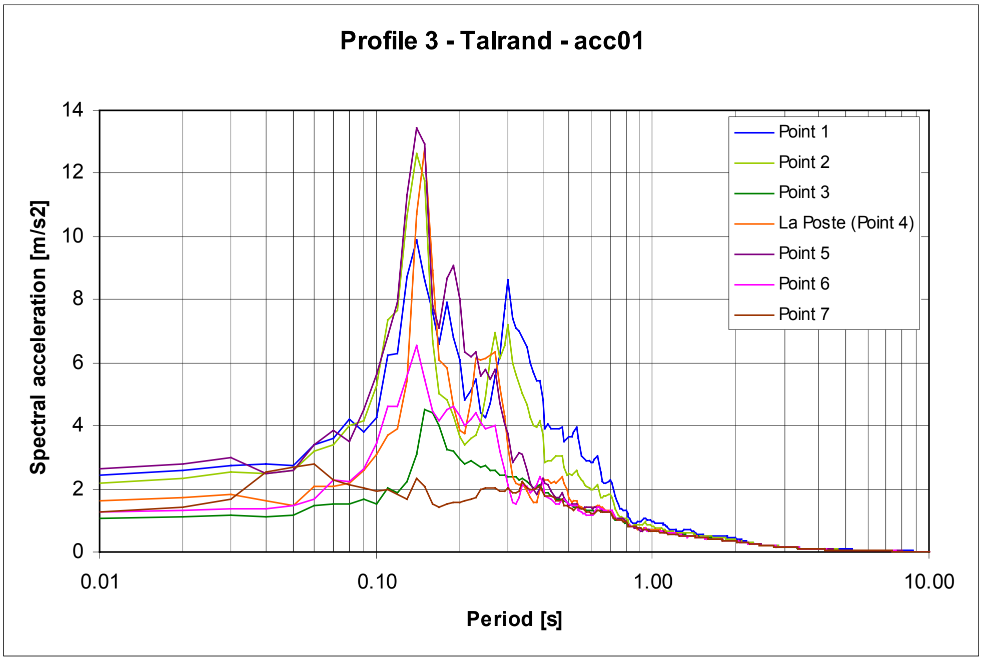

Figure 9. Strong basin edge effect observed at different points along the "edge of the valley" ("Talrand" in German)

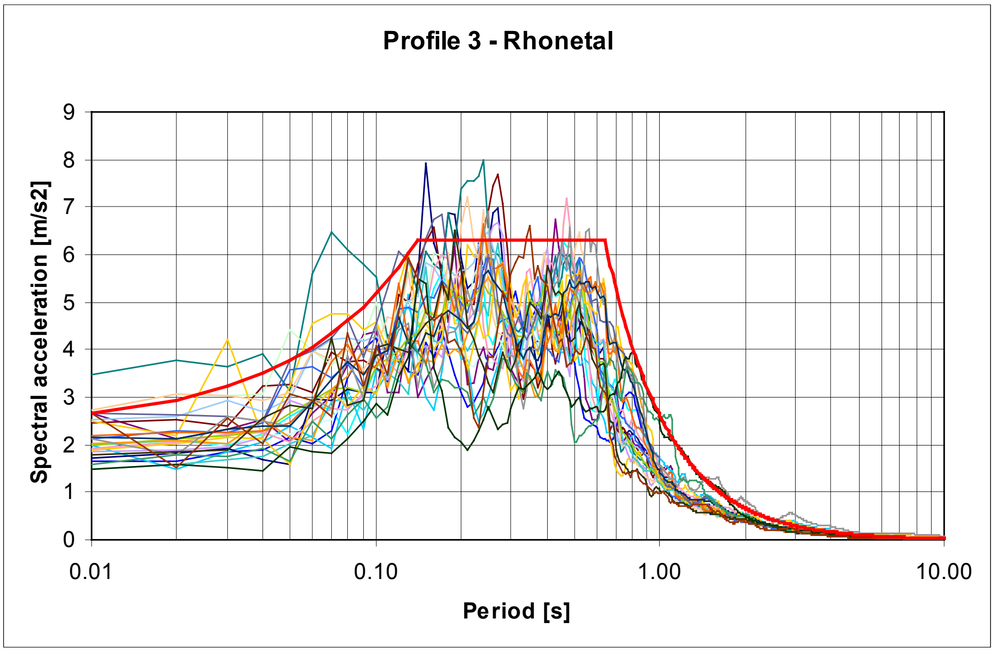

Figure 10. Response spectra resulting from the computations in the valley centre. The red curve is the proposed elastic design spectra for the corresponding zone

As described in the "Procedure" chapter, the final response spectra have been computed for each point, each input motion, and with the different varied parameters. Then, these spectra are shown together, for each zone where they have a similar shape. In the case of the area of Visp, three zones are distinguished, based on the results, within the valley : the valley centre, called "Rhonetal", the edge of the valley, where the basin edge occurs, called "Talrand", and the lateral torrential cone area, called "Schuttkegel".

Figures 10 and 11 show these spectra for zones Rhonetal and Talrand, respectively, as an example. On each of these figures, all spectra are presented, including the account for the uncertainty on the velocity profile, input motion, incidence angle, and for several positions within each zone. The aim of a microzonation study is to define site specific spectra that better account for the local site effects, than the average spectra proposed in the building codes. The next step is then to use the results obtained in order to draw simple "code type shaped" response spectra, for each zone. Out of the computed spectra, a unique design spectrum is chosen for each zone (red curve), rather in a conservative manner, to cover all the above mentioned uncertainties.

For the surface rock areas, the proposed spectrum has the shape of a class A code spectrum, but anchored to the value of the regional hazard on hard rock at the frequency of 10 Hz.

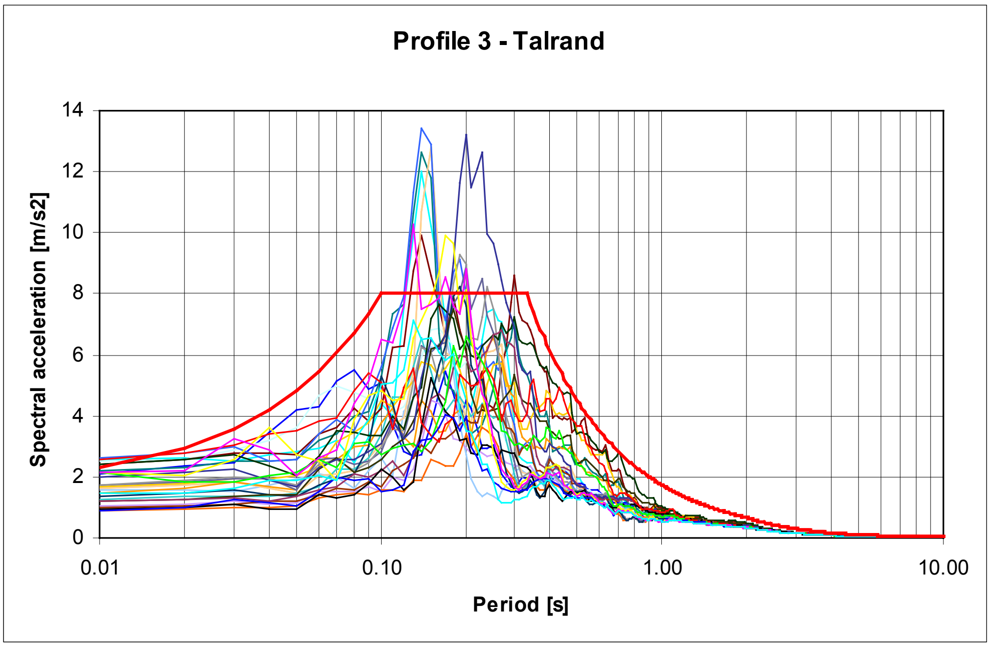

Figure 11. Response spectra resulting from the computations where the basin edge effect occurs. The red curve is the proposed elastic design spectra for the corresponding zone

SEISMIC MICROZONATION OF VISP

The zones to which the above spectra are attributed have to be delimited on a map. To do this, several aspects are taken into account, such as : the shape of the bedrock, the geology of the deposits, the resonance frequency distribution, the surface topography, as well as the parcels or roads for the fine drawing of the limits. Figure 12 shows an extract of the seismic microzonation map of Visp. The shape of the spectra associated to each zone is also given on the map.

Figure 13 shows the elastic design spectra proposed for each zone. These spectra are compared to the code spectra, that should have been used without accounting for the specific 2D site effects. This shows that for periods shorter that 1s, the code spectra underestimate the local site amplification, whereas for longer periods the code spectra are rather too conservative.

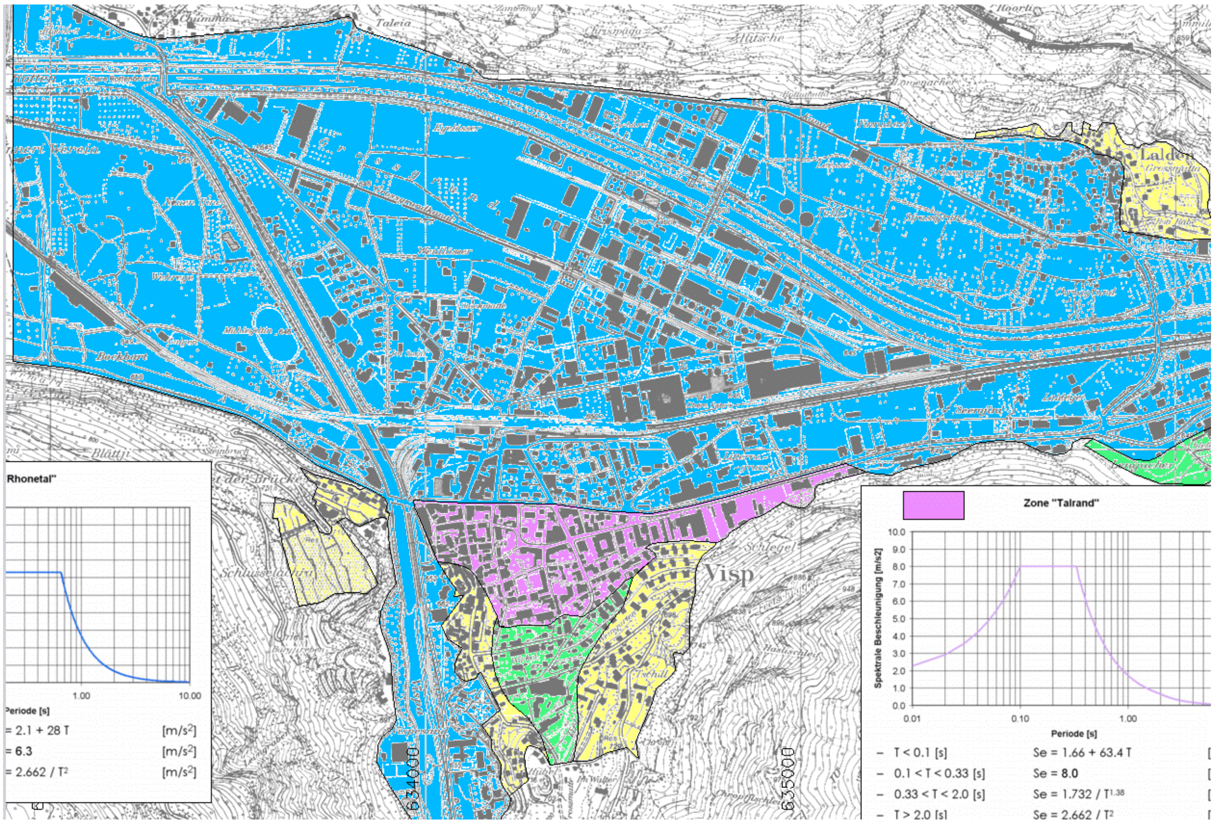

Figure 12. Extract of the seismic microzonation map of Visp

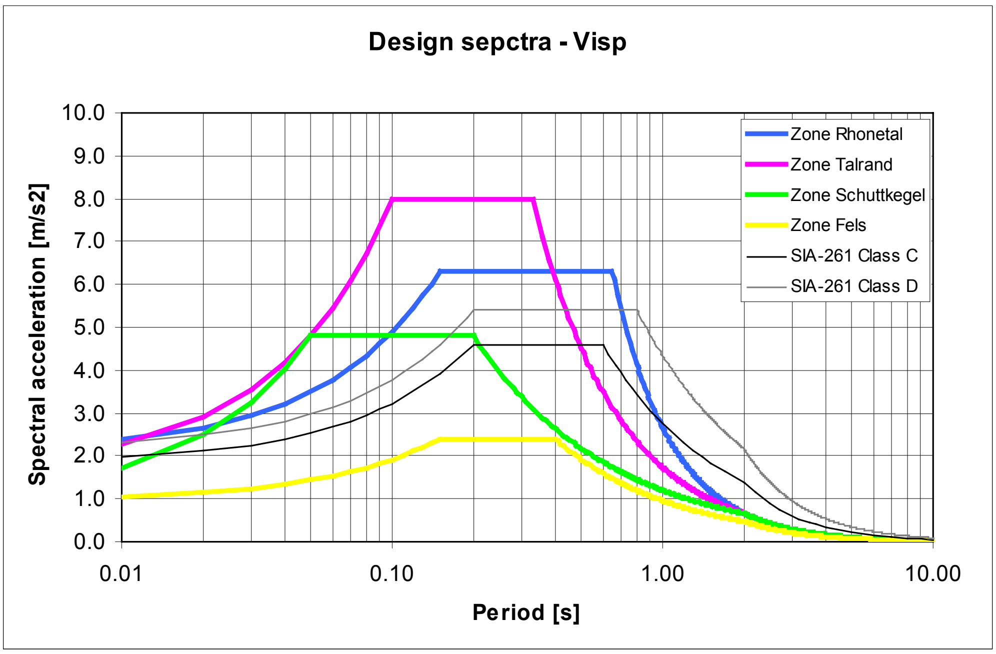

Figure 13. Proposed elastic design spectra (5% damping) in each zone, compared to the code spectra, that would be used without accounting for the specific 2D site effects (in grey)

CONCLUSIONS

A new computation tool has been developed, in the framework of the Sismovalp European project, in order to model the site effects in 2D valley areas, such as alpine valleys for example. This equivalent linear 2D Aki-Larner code has been applied to the seismic microzonation of the area of Visp (upper Rhone valley, Switzerland).

The final objective of such a study is to develop site specific spectra that account for the local site effects and that are used instead of the average code spectra. The seismic microzonation map, showing the zones where these spectra have to be used, is then a tool that can be used directly by engineers for the seismic evaluation or design of structures in the corresponding region. The results of this study are daily used now, as is has become mandatory to use the site specific spectra instead of the building code average spectra.

AKNOWLEDGEMENTS

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