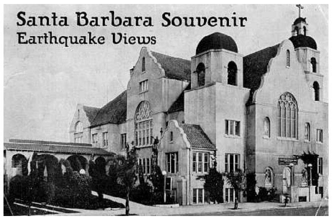

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SITE CHARACTERISATION STRATEGY FOR THE SWISS STRONG MOTION NETWORK

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ABSTRACT

Characterizing the soil structure underlying a seismic station installation is a key issue in engineering seismology. Recordings cannot be used at their full potential without a basic knowledge on the site response. This implies however an effort in geophysical and geotechnical investigations as well as in data storage and dissemination strategies.

In 2009, the renewal project of the Swiss Strong Motion Network (SSMNet) was launched with the objective of installing in its first phase 30 state-of-the-art strong motion free-field stations and proposing a full site characterization for each of the chosen sites. Among the available techniques, ambient vibration array measurement was selected as a standard tool to derive the 1D velocity structure at each site. Because of the intrinsic limitation of passive techniques at high frequencies and for rock sites, however, active surface wave measurements (MASW) are also performed in some cases. At sites suspicious for possible non-linear effects, in situ and laboratory geotechnical tests will be performed.

This paper summarizes the strategy for the site characterization of these new stations: the parameters of interest, the effort in geophysical and geotechnical data collection and the foreseen storage of the data.

INTRODUCTION

High quality strong motion data include, on one hand, high-quality recording instrumentation and housing and, on the other hand, a full characterization of the installation site. Strong motion recordings cannot be properly interpreted without adequate knowledge of the main geophysical and geotechnical properties of the site where they have been recorded. Given the large quantity of data that will be available in the upcoming years, these high quality data will be preferably used for scientific purposes. For example, ground motion prediction equations (GMPEs) are generally considered to be state-of-the-art models only if amplification due to local sites effects, either represented via soil or rock categories, or as a continuous function of the shear-wave velocity (Vs) of the subsurface layers, are explicitly taken into account (Douglas *et al.*, 2010). The number of relevant parameters to characterize sites with respect to their response to earthquakes is also potentially increasing and such site characterization should not be static, but should incorporate more and more information. We based this work on our experience (Fäh *et al.*, 2009) and recent work on the American (Chiou *et al.*, 2008), Turkish (Sandıkkaya *et al.*, 2009) and especially Italian (Luzi *et al.*, 2010) strong motion databases and further developed the ideas behind these databases.

The Swiss Strong Motion Network (SSMNet) is currently made of about 45 continuous real-time stations and 70 dial-up stations (Clinton *et al.*, 2011). Started in 2009, the renewal project of the SSMNet aims at installing 30 state-of-the-art strong motion stations (15 replacements, 15 new sites) in free-field conditions and proposing a full characterization for each of the chosen sites. Free field conditions are achieved using a concrete vault embedded and anchored with steel bars in the ground. Several geophysical methods are conducted, depending on the site, in order to derive the main geophysical properties of the underlying soil or rock. Data will be stored in a PostgreSQL database feeding CMS-based (Content Management System) web pages for each station providing a dynamic station book, including cartography and graphics. This paper summarizes the strategy followed for the site characterization of these new stations: the parameters of interest, the effort in geophysical and geotechnical data collection and the foreseen structuring of the data .

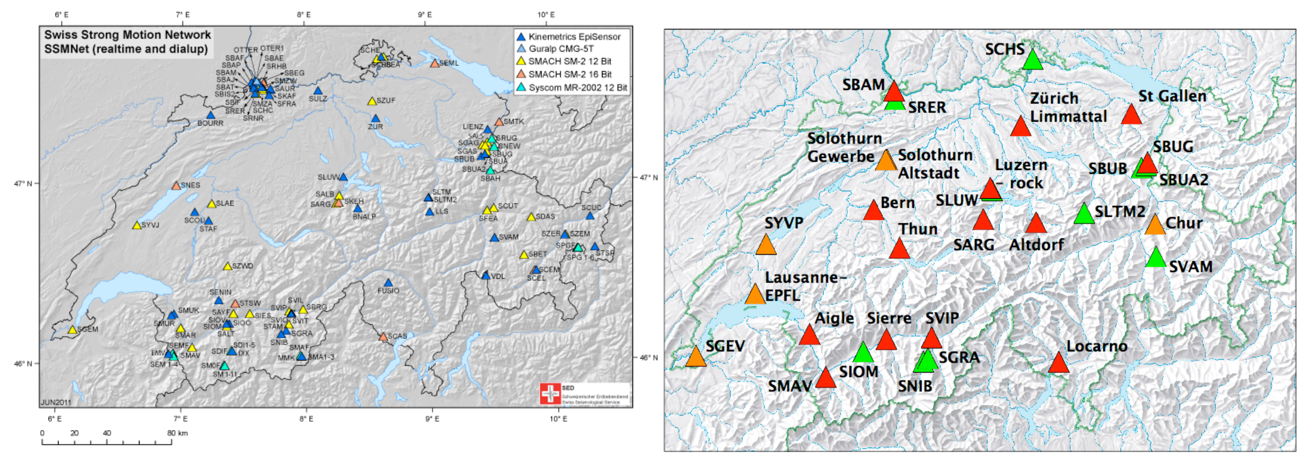

Fig. 1. Swiss Strong Motion Network (left) and sites concerned by the SSMNet renewal project (right) (status on July 1st 2011).

RELEVANT PARAMETERS FOR SITE CHARACTERISATION

Effects of surface geology on seismic motion can have very different origins. Parameters that will influence them are geometry of the underground structure (layering and basin effects), the constitutive model of the underlying soil (linear and non-linear) and topography. Many attempts are described in the literature to parameterize and classify local ground motion amplification behavior. Within the framework of the aforementioned renewal project of the SSMnet, the relevant parameters are collected based on existing data and new geophysical measurements.

Topography and geology

The most simple and accessible information about a site that have an influence on local amplifications is provided by geological, geotechnical and topographical maps. They include the altitude and slope of the terrain, and geotechnical and geological information about the near-surface layers. The slope may be a relevant parameter as it provides a proxy for the expected topographical amplification at the site. Further, Allen and Wald (2007) proposed slope-to-Vs30 and Vs30-to-ground motion amplification relationships to be used for ShakeMap applications. The relevance of these parameters can be validated a posteriori using the recorded earthquake data.

Geometry and mechanical properties

Site characterization should in theory provide as much information as possible for data analysts (e.g. GMPE developers) as well as modelers that would be interested in building 1D, 2D or 3D, linear or non-linear model to estimate the seismic response of the site. This includes, when available, information about the geometry of the site (layering) and the mechanical properties, linear and non-linear, of the different layers, as well as the depth of the water table. For state of the art site characterization using low-cost geophysical methods, we are generally limited to 1D information. Even for 1D properties, non-uniqueness of inversion procedures makes the choice of a single velocity profile impossible. When borehole data is available from the surroundings, it can be used to cross-check the inversion results.

In addition to the explanatory parameters described hereafter, simple parameters for the geometry need to be provided to help the user selecting a station. Emphasis is on site effects, including a basin flag for stations on sedimentary basins, the geometry of the underlying basin (1D/2D/3D), the distance from basin edge or the bedrock depth.

Explanatory parameters

Geophysical data allow to reliably derive explanatory parameters proposed in the literature to represent local amplification. An extensive list of such parameters is provided for each station. These parameters can describe the ground stiffness using for example the soil classes of the building codes (EC8, SIA261, NEHRP) or estimates of the travel time average velocity, such as Vs-z (average S-wave velocity over the top 5, 10, 20, 30, 40, 50, 100, 200 m) and the quarter-wavelength velocity as function of frequency (Joyner *et al.*, 1981). Other parameters are related to the measured and modeled amplification, such as site-to-reference and H/V spectral ratios, empirical amplification from residual analysis of low magnitude earthquakes, the quarter-wavelength amplification and the 1D-SH transfer function. When available, these parameters are provided with their standard deviation.

GEOPHYSICAL DATA COLLECTION

In the frame of the renewal project, new geophysical data is collected at the station sites. Among all the available techniques, ambient vibration array processing was selected as a standard tool to derive velocity profiles. Moreover, at some sites of particular interest, active seismic and laboratory tests on core samples are performed.

Ambient vibration array analysis

Arrays of 14 sensors are generally placed in concentric circles of different diameters. Measurements are performed as close as possible to the strong motion stations (e.g. Fig. 2). We are using Lennartz 3C 5s seismometers and Quanterra Q330 dataloggers, synchronized by GPS. Depending on the site, several configurations are performed in order to extract dispersion curves on the widest frequency range possible. For stations in high-noise environment like cities, recordings are performed during the night. Considering that the installation time and cost of the permanent station is not negligible, recording duration is chosen at least 90 min, and up to 180 min for night recordings. Location of the sensors is measured using the Real Time Kinematic technique provided by Swisstopo on a Leica GPS device, ensuring a 3 cm absolute location precision.

Recordings are processed using the high-resolution FK method (Capon, 1969) both on vertical components only (Geopsy software http://www.geopsy.org) and on 3C data following Fäh *et al.* (2008). Love and Rayleigh dispersion curves are then selected from the results of this processing (e.g. Fig. 2). The inversion of 1D velocity profiles is performed using the Dinver software that implements the modified Neighborhood Algorithm (Wathelet, 2008). Love and Rayleigh dispersion curves and the right flank of the H/V curve are used, when available, for the inversion. Different parameterizations are used in order to extract a set of candidate profiles matching the data, including free and fixed depth layering. Computations of derived parameters (see previous section) are performed on this selection, including the resulting standard deviation. Figure 3 shows the selection of profiles for the array described on Fig. 2 as well as compare several proxies for amplification: site to reference spectral ratios for ambient vibrations, SH transfer function from the selected profiles and quarter-wavelength proxy for amplification (Joyner *et al.*, 1981).

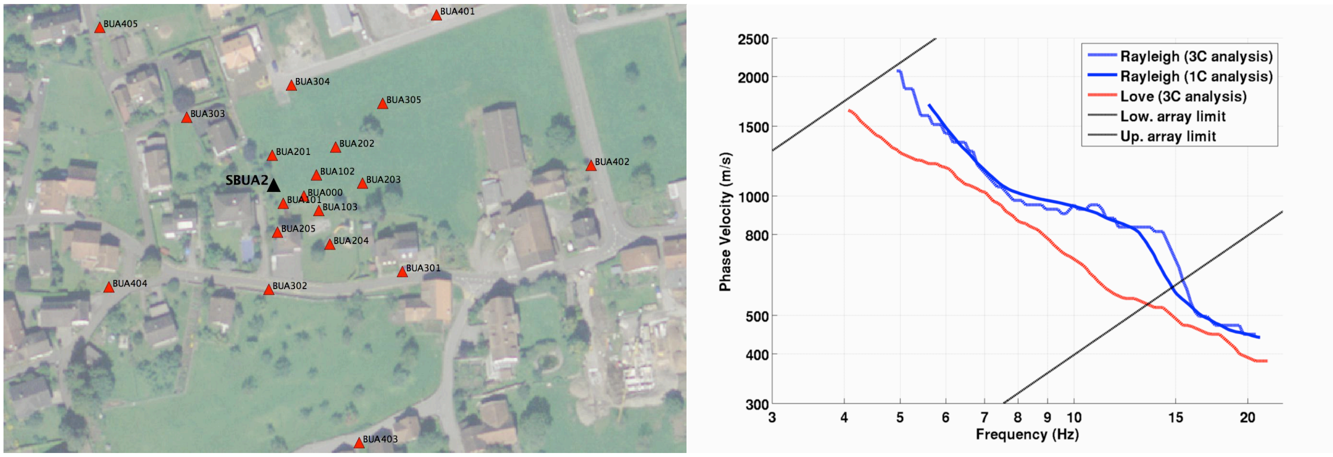

Fig. 2. Array recordings performed close to the station SBUA2 (2 configurations) and obtained dispersion curves.

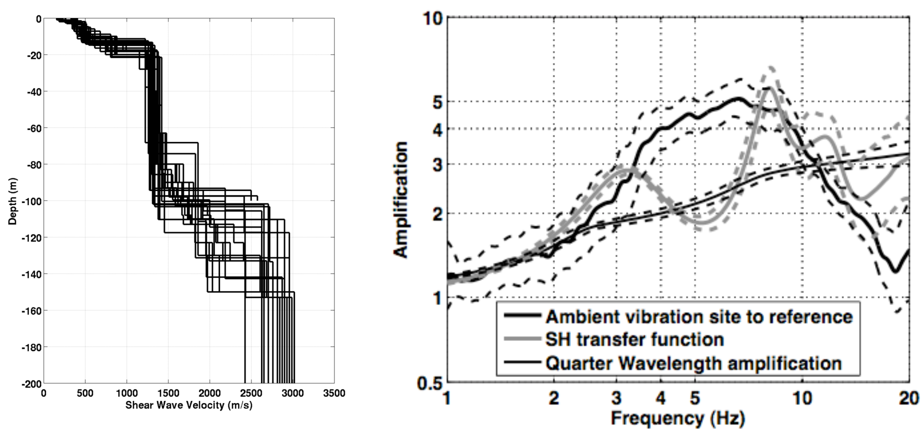

Fig. 3. Selected velocity profiles from the inversion (left) and frequency dependent proxies for amplification.

<u>Ambient vibration single station measurements</u>

Array recordings are also processed using the H/V spectral ratio technique to reliably assess the fundamental frequency of resonance at the station, and to detect lateral heterogeneities within the array. Up to 5 different processing methods are used, both classical and time-frequency analysis (Fäh *et al.*, 2009). In cases where a 2D effect is suspected (e.g. Roten *et al.*, 2006), polarization analysis following Burjanek *et al.* (2010) is performed in order to correctly interpret the H/V results. Moreover, in some cases, extensive single station measurements are performed around the station in order to map the variability of the underground conditions, especially the fundamental frequency of resonance to estimate the bedrock depth. Figure 4 shows the example of a survey performed around station SBUA2, located on an alluvial fan.

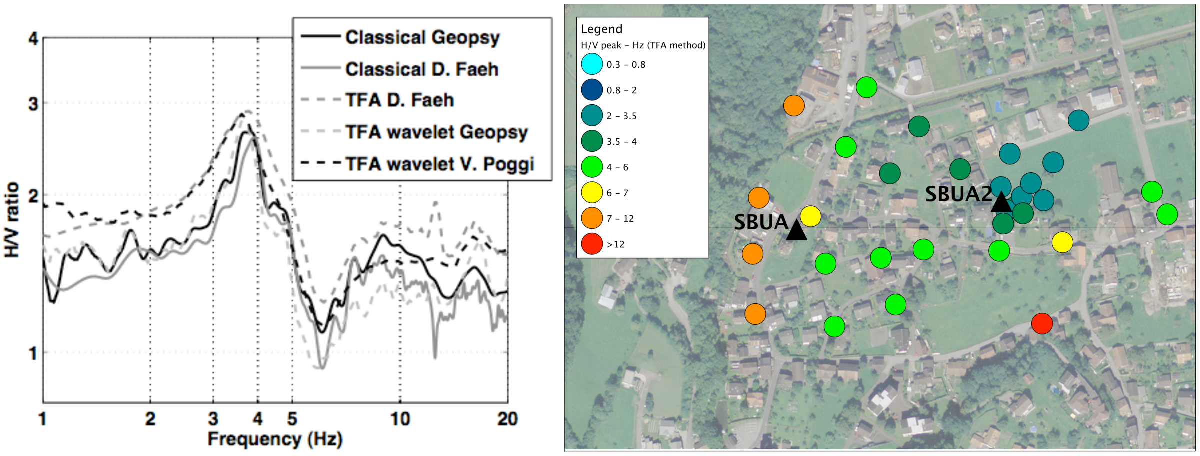

Fig. 4. H/V ratios of the central point of the array SBUA2 using 5 different processing techniques (left); Map of the H/V peak frequency around the dial-up station SBUA and the renewed station SBUA2 (right).

Active experiments

For sites of particular interest, active source surface wave analysis is performed together with passive acquisition, following the time-frequency-wavenumber method proposed by Poggi *et al.* (under review). This approach is based on continuous recordings, and the uses wavelet transform to analyze and extract the phase velocity dispersion of surface waves. This method is particularly suitable when using seismological (continuosly recording) equipment and in combination with ambient noise measurements. Combining active and passive acquisition allows the investigation of dispersion curves over a broad range of frequencies, and to extend the resolution and depth of the final velocity profile.
Moreover, for rock sites that could not be characterized using ambient vibration surface wave methods, as remarked by Pileggi *et al.* (2011), other active methods will be tested.

Laboratory test

On sites where non-linear effects may occur, core sampling is foreseen. These sites are characterized by weak lacustrine sediments (Lucerne, Yverdon) or water-saturated sand layers in large alpine valleys (e.g. Rhone valley), where liquefaction was observed in past events. In the frame of the COGEAR project (http://cogear.ethz.ch), 3 borehole strong motion stations as well as deformation monitoring will also be installed at such a site in the Rhone valley in Visp.

DATABASE

The information collected for each station of SED networks, including the new strong motion stations, will be stored in a PostgreSQL database. A new model was designed including two main types of objects: sites and experiments. Geophysical and geotechnical results of data analysis are first modeled as properties of the providing measurements/experiments, and then linked to instrument sites. Every experiment is detailed in the database, including intermediate processing steps of interest. The scheme is flexible enough to allow full transparency on the provenience of a site assessment and its uncertainty, also in situations where it is the result of multiple experiments with results varying between datasets and analysis methods.

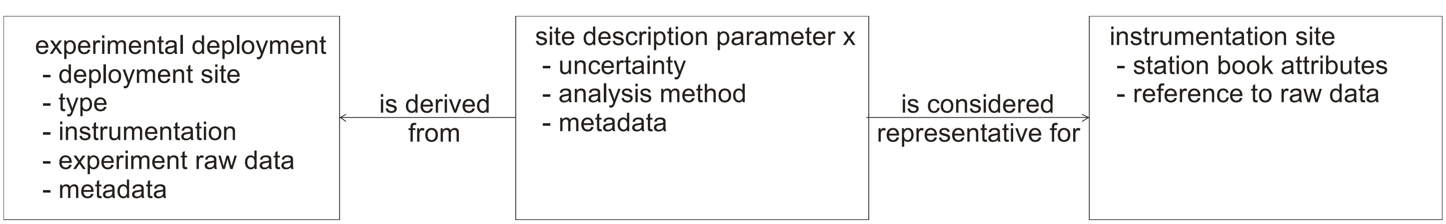

Fig. 5. An adequate data model for information used in site assessment allows transparency, quality control, and review.

In the future, CMS-based webpages will provide access to this database and provide a dynamic, interactive station book. This will contain graphics and integration of 3rd party geographical data using OGC web map services. Moreover, access to the station raw data and broadband data of the SED networks can now be efficiently linked in by referencing to the SED Arclink server (arclink.ethz.ch).

CONCLUSIONS

In the framework of the SSMNet renewal project, a new strategy to characterize the sites at seismic stations was developed and is currently applied that allows full transparency over raw data of geophysical experiments, analysis method, and application of the results for site characterisation. The status of the renewal project can be followed on the webpage of SED http://www.seismo.ethz.ch/research/groups/risk/projects/SSMNrenewal/. Station metadata will soon be available on the Web for the engineering and seismological community, as well as the general public. Waveform data from SED SSMNet stations are available at arclink.ethz.ch, data of temporary deployments are generally restricted to SED use only.

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