Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

SED
Schweizerischer Erdbebendienst
Swiss Seismological Service

BAFU Report

Guidelines and strategies for implementation of seismic site response in risk tools

Part II

SED dataset overview and proposals for implementation

Poggi Valerio & Donat Fäh

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Available datasets

In the following, we provide a description of datasets owned by the Federal Office of Topography (Swisstopo), cantonal offices, and universities or available at the Swiss Seismological Service (SED). These datasets are of potential interest in the development of new strategies for site response analysis, in site-response assessment and microzonation at different scales (national, regional, local). The goal is to present an overview of the different datasets in terms of amount and quality of the available data, usability of the interfaces and potential use for the calibration of site amplification models and related proxies. As a conclusion, we propose a strategy for the implementation of site response at national scale in a future risk modeling tool.

1. Geological, geotechnical maps

Geological, lithological and geotechnical maps are available in digital format (vector or georeferenced raster) from Swisstopo. These maps provide a first order representation of the main exposed geological units at different resolutions (1:500’000 to 1:25’000) and can be used as discrete proxy for seismic soil classification at level I (national) in combination with other information, such as surface topography, resonance frequency and sediment thickness. Direct application to level II (regional) and III (local) is however discouraged, due to the unavoidable oversimplifications used in describing the different units when compared to the true local variability; for analyses at regional and local scale, direct measurements and reinterpretation of available data (borehole, geophysical, geotechnical) should always be preferred.

Available geological information in Switzerland has been homogenized within the project GeoCover (figure 1). The project had the goal of providing high quality vector description of the surface geology, including data from the previous Geological Atlas of Switzerland (1:25’000) and a compilation of special and unpublished geological maps at various scales. Conversely, the geotechnical map of Switzerland 1967 (1:200’000) of the Schweizerischen Geotechnischen Kommission (SGTK) is out-dated. An update has been planned for years, however the final product is not yet available.

Geotechnical and geological ground types can be used as a proxy for the estimation of mean site response over large areas, for instance by computing for each soil type the average seismic amplification from several empirical observations in the different frequency bands of engineering interests. With such simplified approach, epistemic uncertainty is expected to be significant, and needs to be carefully assessed. The advantage of such data is that hazard potential can rapidly be mapped over large areas by using GIS tools.

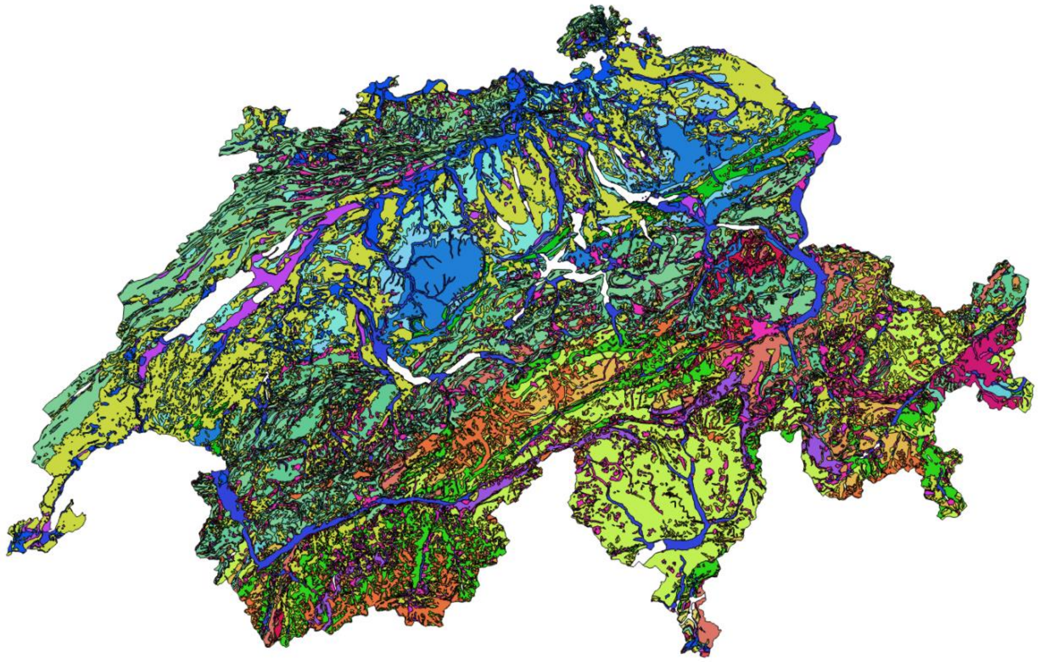


Figure 1, *Geological Atlas of Switzerland 1:25'000 (from Swisstopo).This dataset is part of the GeoCover project, which also integrates special studies at higher resolution.*

2. Soil classes

In order to facilitate the selection of the appropriate design spectrum of the Swiss Code SIA 261, the Federal Office for the Environment (FOEN) has supported cantonal soil-class maps showing 6 soil classes from A to F. The soil classes A to E for which a spectrum is given in the building code are shown in Table 1. Soil class maps are generally based on indirect evaluation of the surface geology and available borehole data. Epistemic uncertainty of the average amplification in the different soil classes is significant and overlapping between classes, as outlined in the PhD thesis by Steimen (2004) (see Figure 2).

A study performed by SED for BAFU (Gassner-Stamm & Fäh, 2014) has demonstrated the limitations of the geotechnical-based SIA 261 classification scheme when compared with direct Vs30 measurements. The comparison between Vs30 values received from geophysical measurements and the soil classes from geology shows discrepancy in about 50% of the cases, mainly if the site has a Vs30 value in the range of soil class B. In the 6 cases of soil class D, the class can be defined correctly from geological assessment. Soil class C assessed by geology in many cases are in fact soil class B or even A. More than 50% of these cases are not correct. Soil class B in the geological assessment is completely absent in this dataset which indicates a methodological problem in the procedure to develop soil class maps from geological information. This was also noted in the PhD by Steimen (see Figure 2). Finally in 5 of 12 cases assessed as soil class A from geology; the assessment is not correct, most probably due to a thick layer of weathered material that could not be identified from geological considerations. Looking at measured f_0-values results using H/V spectral ratios indicate a rather good separation of soil class A and soil class E.

These results clearly show that indirect extrapolation of geological/geotechnical classes alone is unreliable. On top of that, the relation between local amplification and site classes is generally non-univocal, and might lead to large errors in the final estimation of the local response, particularly when assessing amplification as a function of frequency. A combination with additional information, such as topography data and measured fundamental frequency of resonance, is therefore advised to define a new set of classes with reduced uncertainty in the site response.

Soil Class	Description	Vs30 [m/s]
A	Stiff or soft rock, covered by at most 5m soil layer.	> 800
B	Cemented gravel and sand and/or preloaded soils (including moraines) with a thickness above 30m.	400-800
C	Normal consolidated and not cemented gravels and sands and/or moraines with a thickness above 30m.	300-500
D	Normal consolidated fine sands and silts with a thickness above 30m.	150-300
E	Surface layer of soil classes C or D with a thickness between 5 and 30m, over soil deposits of class A or B.	-

***Table 1:** Definition of soil classes according to the Swiss Code SIA 261 (2003). The existing soil class maps published before 2015 refer to this definition. The description in the 2014 version of the code was changed towards a geotechnical description.*

3. Digital elevation models and topography data

Digital elevation models (DEM) are available from Swisstopo at a resolution of 25m (Figure 3) and as small as 2m (SwissALTI3D). This information has a large potential for the use as continuous proxy in site response analysis both at large scale and for local studies, e.g. as input for direct numerical modeling. The main advantage is the possibility to perform automatically rapid calculations over large areas and at high resolution using standard software.

Nowadays, the large potential of using topographic information in site response analysis has not been fully exploited. Examples on effectively using topographic information are available in literature; in recent studies (Wald and Allen, 2007) slope gradient was used to assess geotechnical soil classes based on Vs30. Such approach, in spite of being widely used at local scales, is affected by considerable uncertainties in the estimation (Lemoine et al., 2012), which makes it unsuitable for the use at national scale without additional information.

In a similar manner, other topography-derived parameters can be useful to better assess geological and morphological features directly related to particular seismic response characteristics. This is the case of relative elevation (difference in altitude to a reference local value) and of topographic convexity (derivative of the slope), which are useful to evaluate deposition energy potential, related to sediment granulometry and ultimately affecting seismic propagation velocity (Stewart et al. 2013). Also texture parameters (such as roughness and pattern correlation length) might be of potential interest, being related to weathering and material type. As well, basin shape parameters (width, elongation), which are important for a first order evaluation of the occurrence of 2D/3D effects, can be derived automatically over large areas. As noted by Burjanek et al. (2014a, 2014b) all these parameters however relate to a specific length scale or wavelength that needs transformation into information in the frequency domain.

Direct influence of topography on ground motion has been extensively (and still is) analyzed in numerical studies. As described in the main report, geometrical effects in amplification can reach values up to a factor of 2, which is much lower than the factors observed during earthquakes. Local amplification is controlled in first place by the sub-surface velocity structure (Burjanek et al., 2014a).

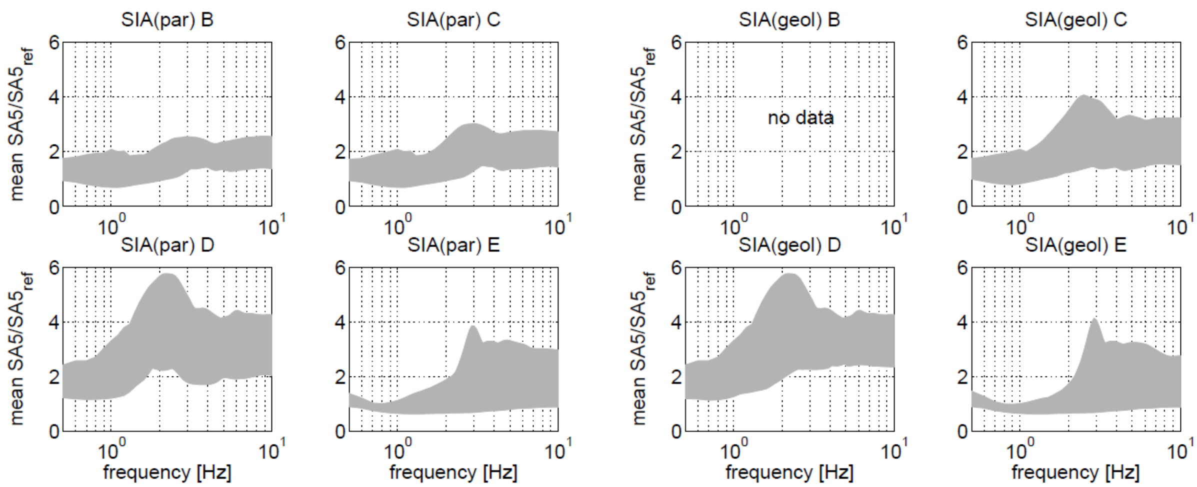


***Figure 2**, Range of mean spectral amplification (5% damping) from 1D numerical modeling, for site classes defined using parametric (left) and geologic/geotechnical (right) definitions of site classes (Steimen,2004).*

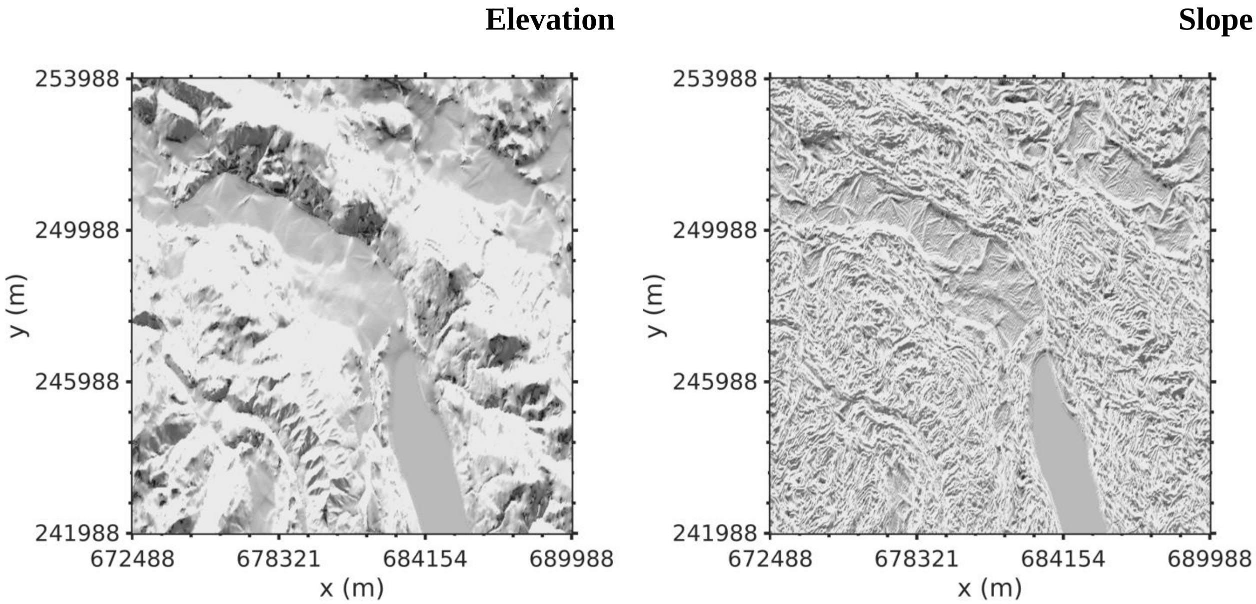


Figure 3, *Digital Elevation Model (DEM) at 25m resolution of the Zurich area. On the right the derived slope (gradient) model to be potentially used as additional proxy for ground type discrimination.*

4. 3D structural models

Within the framework of the transnational project GeoMol 2007-2015 (http://www.geomol.eu) partners from Austria, France, Germany, Italy, Slovenia and Switzerland are collecting data on the geological structures of the Molasse and Po basins. Swisstopo is the coordinating institution in Switzerland, and GeoMol will provide 3-dimensional subsurface information of the Molasse basin in the Swiss Foreland. Such information will help to improve regional seismic hazard assessment in the Swiss Foreland. Moreover, Swisstopo initiated project GeoQuat related a 3D model of quaternary in Switzerland. An initial model derived from different studies since the 1980ties was implemented at Swisstopo, but was recognized to be highly heterogeneous in quality. For this reason, a pilot study was lunched to improve this model in four areas (Birrfeld, Vierwaldstättersee, Aaretal, Visp) based on the analysis of additional data, in particular gravimetric and borehole data. Such pilot study allows to estimate the effort for a Swiss-wide 3D model of the quaternary. The usefulness of the existing 3D information would need further investigation in order to define regional reliability of this information as input for site-response analysis. In the long run, 3D models from project GeoQuat together with the assembled gravimetric and borehole data would be highly valuable datasets for level II studies, and in the end for level I studies as well.

For some areas (e.g. the wider Basel area) 3D geological models exist (Fäh & Huggenberger, 2006) and would need integration in GeoQuat and GeoMol.

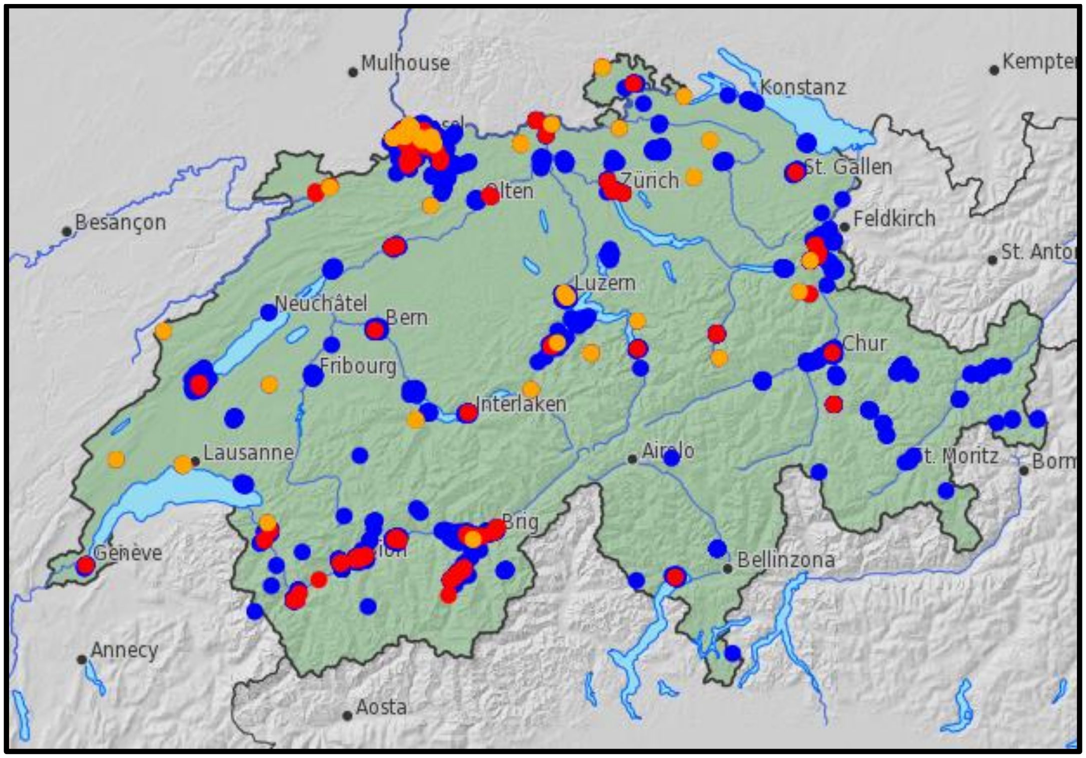


Figure 4, *Overview of investigated sites from the SED site characterization database. In blue the sites with H/V spectral ratio only; in red the sites with array measurement of ambient vibration (and H/V spectral ratios); in orange the sites investigated with active seismic techniques (MASW).*

5. H/V spectral ratio and f_0

The Swiss Seismological Service has collected over about 20 years a remarkable amount of single-station ambient vibration recordings (around 3500) at sediment sites. For each recording, the horizontal-over-vertical (H/V) spectral ratio has been computed and the result stored into a database for easy access. Over the years the data formats changed and the analysis software progressed. For level I and II applications this would consequently need some reanalysis with homogeneous treatment. This H/V database is continuously extended with about 100-200 sites per year. Integration with data from external databases (e.g. from companies) is also possible and can be desirable.

Together with H/V curves, the database provides direct estimates of the picked soil's fundamental frequency of resonance (f_0) and the H/V amplitude at f_0. This information is valuable because provides a major constraint for the definition of depth and seismic impedance contrast of the geophysical bedrock, as well as qualitative information about the amplification as a function of frequency. In combination with direct estimates of the local (average) seismic velocities and empirical amplifications, H/V data allows a discrimination of areas with similar seismic response at level II and III. This issue is a particular area of research that is recommended for further investigations.

H/V information is also correlated with geometric/topographic features of the basin and can be used as base for microzonation at level II together with geological/geotechnical soil classification. In particular, f_0 and directional H/V amplitude might be used to adjust the regional amplification factors by adding ad hoc 2D-resonance aggravation parameters.

6. S-wave velocity profiles

The SED site characterization database consists of a collection of 181 sites (figure 4) investigated using both ambient vibration methods (127) and active seismic techniques (54). For each site, data from measurements, processing results and summary reports (e.g. Michel et al., 2014; Poggi & Fäh, 2014) are collected and made accessible through database-interface, direct file access or using specific MATLAB APIs. This database is homogeneous in its structure and is continuously extended with 10-20 sites per year. The potential integration of measurements done by companies was discussed, however never realized due to financial and sometimes legal restrictions.

The site database is structured to offer a common interface to the different datasets such as velocity profiles (Vp and Vs, figure 5), derived engineering parameters (average travel-time velocities, quarter-wavelength parameters and analytical amplification functions) and meta information (dispersion curves, ellipticity of Rayleigh waves). The data are homogenized in a standard format to facilitate any subsequent analysis. It has to be noticed that for each site the database provides a number of plausible velocity models, in order to represent the variability of the local conditions and the uncertainty of the analysis. The derived parameters computed as average from all velocity profiles have an estimate of the error according to parameter-specific statistic.

The database is relevant to the definition of spatial proxies based on direct measurements (e.g. Vs30 and f_0 classes) and for the calibration of prediction equations accounting for local ground motion estimate (e.g. site amplification and attenuation; Poggi et al., 2012; Edwards & Fäh, 2013; Edwards et al. 2013) and site models (e.g. generic velocity profiles; Poggi et al. 2011, 2013). To do this, combined analysis with other database is essential, particularly with the empirical amplification, the H/V dataset, local soil composition and thickness.

a) STIEG (Active) **b)** HAMIK (Passive)

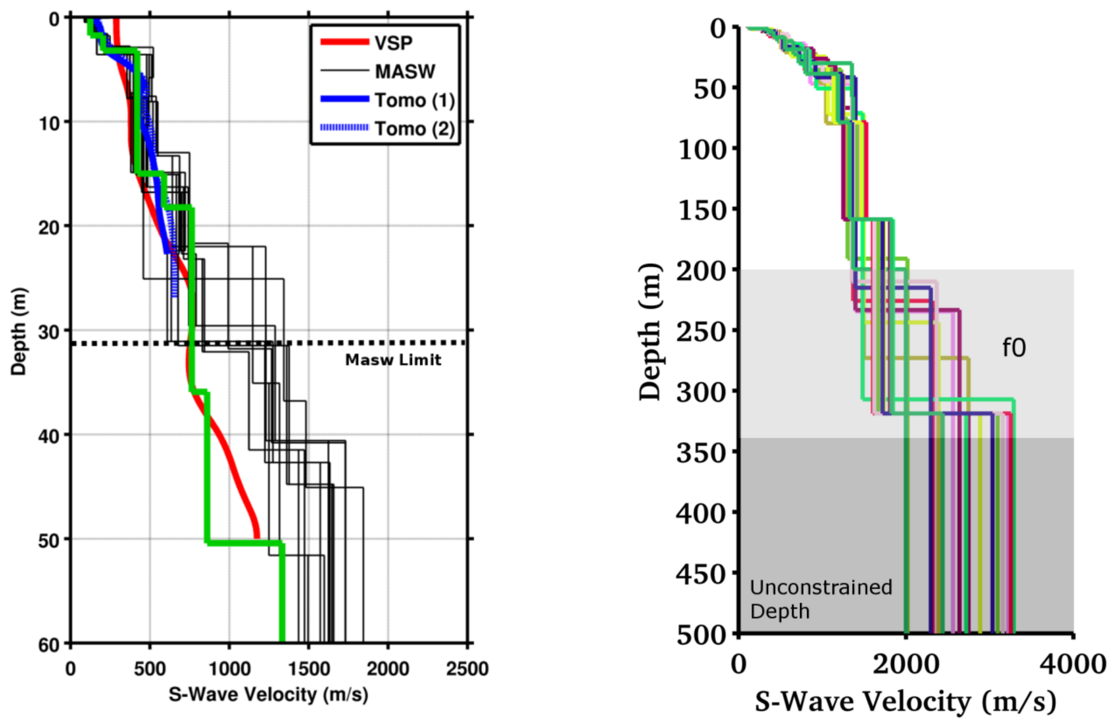


Figure 5, *Example of shear-wave velocity profiles (Vs) from the SED site characterization database (Poggi & Fäh, 2014). On the left, the results from active seismic processing (station STIEG) and on the right results from array analysis of ambient vibrations (station HAMIK). For each site, a set a plausible velocity models is provided, to represent the uncertainty of the estimation.*

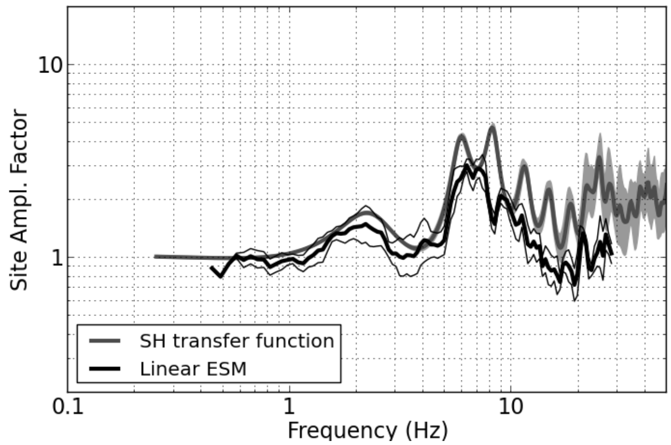
7. Empirical amplification functions

For each real-time station of the Swiss networks (SSMNet, SDSNet) an empirical estimate of the site amplification function (both elastic and anelastic) and related uncertainty are available. The functions are obtained from spectral modeling and inversion of a large number of small-magnitude events (Edwards et al., 2013). The amplification is referenced to a unique common rock profile (Poggi et al., 2011). Procedures for recalibration to any arbitrary reference condition are available (Michel et al., 2014).

Together with the site characterization database, the catalogue of empirical amplification represents one of the most valuable information for the calibration of generic amplifications functions (level I) and regional model verification (level II and III), as it represents the “true” observed ground motion amplification at controlled sites.

The SED has already proposed several studies about the implementation of local amplification predictors based on the comparison between observed empirical amplifications and velocity proxies (particularly the quarter-wavelength parameters), but many possibilities are still to be investigated. This is the case, for instance, of predicting amplification directly from H/V spectral ratios of ambient vibration, or the calibration of aggravation factors for 2D/3D effects based on topography information.

a) SARK



b) SBEG

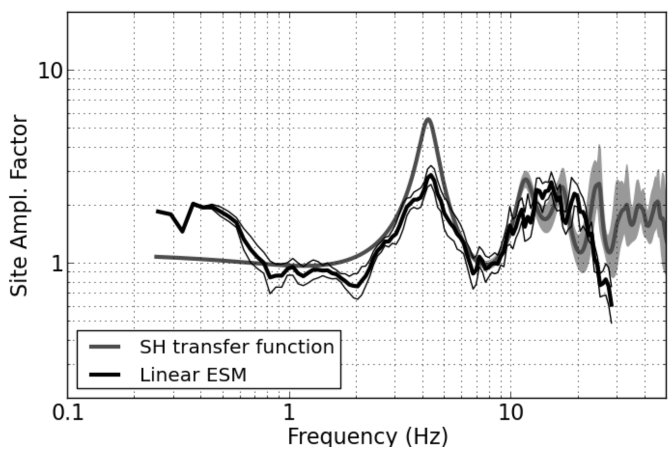


Figure 6, *Example of empirical Fourier amplification functions (ESM, in black) and numerical modeling results (in gray) from the SED station and site characterization databases. These data are the base for the calibration of the site response factors for the different ground types.*

One issue when using this database is the identification of the amplification functions in so-called free-field conditions. On a total of 271 available stations, 63 are effectively free-field, while 102 are urban free-field (free-field within a city and therefore with potential influence of nearby structures), 36 are inside civil buildings, 29 in tunnels, 27 in dams, 9 are borehole sensors and 2 are located in caves. Not properly accounting for this issue might introduce bias in the definition of any derived amplification model.

In addition to the described data, SED also derived empirical amplification functions for the KIK-Net stations in Japan (more than 600 sites). For most of the sites, measured Vs profiles and geological logs are available. The reliability of the Vs profiles were checked in Poggi et al. (2012, 2013) and the reliable profiles identified. The geological information is however not in a database, and would need an interpretation in terms of geological nomenclature applied in Switzerland.

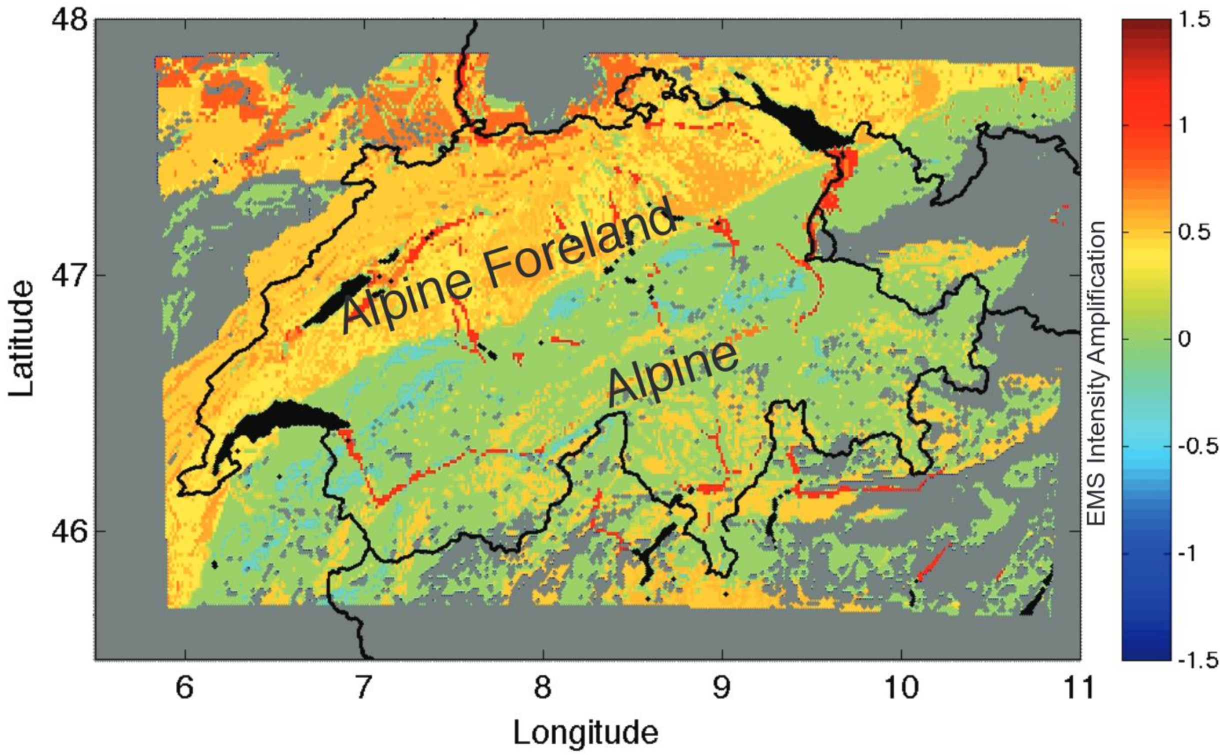


Figure 7, *Map of EMS Intensity amplification factors available in Switzerland. These amplification factors are defined relative to the ECOS (Earthquake Catalogue of Switzerland) macroseismic attenuation relation (SED, 2011).*

8. Macroseismic data

Macroseismic information is routinely collected by SED after noticeable events. The macroseismic data is validated manually, and stored in digital format in a dedicated database. This database comprises also reports from sources related to historical events. The macroseismic intensity dataset includes around 35,000 intensity assignments collected from 17,000 settlements in Switzerland and for 720 earthquakes since 1850 (Kaestli and Fäh, 2006), as well as macroseismic data for the time before 1850 and all known events that reached intensity VI.

An example application of the use of macroseismic data is the compilation of the EMS intensity amplification map of Switzerland (figure 7). The amplification factors are defined relative to the ECOS (Earthquake Catalogue of Switzerland) macroseismic attenuation relation (Fäh et al., 2003) and calibrated on geological soil classes as documented in Appendix D in Fäh et al. (2011). The mapped values refer to another rock reference condition than the one used in the calculation of the empirical amplification functions. This should be accounted for by a constant correction term ~ +1/2 intensity units (namely 0.47) that accounts for the necessary adjustment to Swiss reference rock (Vs30~1105 m/s). This macroseismic amplification map was implemented in the ShakeMap tool at SED, and tested in combination with the Swiss stochastic ground-motion prediction equation, in the sense, that we can reproduce the general shape of observed macroseismic fields of the strong historical earthquakes in Switzerland (Cauzzi et al., 2015). Uncertainties related to these amplifications were never assessed so far, but will be an important issue in the context of a seismic risk model for Switzerland.

Macroseismic information can also be used in support to regional studies for the identification of areas of anomalous seismic response. The sites are documented in Appendix D in Fäh et al. (2011). Due to the large uncertainty, however, this information should always be complemented with other types of observation.

9. Integration of local studies

Several site response studies are available from SED for integration into a potential risk model of Switzerland. For other studies, e.g. by private companies, it is not clear if the relevant information and data were derived and are accessible. The level of detail of these studies is different, ranging from complete regional microzonation (e.g. Basel area) to local models.

Among these, it is worth to mention:

- Microzonation of Basel (Fäh & Huggenberger, 2006)
- Multi-hazard analysis of the Visp area within project COGEAR (Burjanek et al., 2012, Fäh et al. 2012)
- Preliminary microzonation analysis of Lucerne (Poggi et al., 2012)
- 3D model for the region of Sion (Roten et al., 2008)
- Several microzonation studies based on engineering methods (e.g. studies of Resonance SA for the cantons VS and VD)

Microzonation studies are generally performed to provide site-specific design spectra related to the building codes. They often contain conservative decisions and the results cannot be directly implemented in risk tools. The problem with such studies might be that intermediate results are not stored, and that expert assessment is used instead of geophysical measurements. A prerequisite for microzonation studies to be useful in a risk model would be the compliance to a set of rules, the elaboration of intermediate results and the verification with earthquake recordings.

10.Natural hazard maps

Based on federal laws, cantons are obliged to produce hazard maps for floods, avalanches, landslides and rock falls and consider them in activities related to land use planning. The hazard maps give an overview of the hazardous situation in five security levels: red, blue, yellow, yellow-white striped, white. They contain information on the causes, sequence, spatial extent, intensity and probability of occurrence of floods and mass movements. Such maps might be of potential use for seismic risk assessment of earthquake-triggered landslides and avalanches. The potential use in level I and II is somehow direct, as the maps can be integrated as a separate additional layer. Moreover, basic data used to derive these hazard maps could be combined with seismological information. This would need additional research with the main target to develop probabilistic models of landslide triggering using ground motions from magnitude-distance pairs derived from the de-aggregation of the seismic hazard.

11.Datasets accessible through SGPK

The Schweizerische Geophysikalische Kommission (SGPK) directly finances and collects geophysical data from many areas in Switzerland. This is the case of gravimetric data, presently used for the pilot study areas in project GeoQuat (see section “3D structural models”). These data are complementary to seismic data and provide information about the three-dimensional density distribution of soils and rock. Interpretation is generally not straightforward and needs particular expertise. The potential use in level I and II would need some further assessment.

The project SAPHYR as well is financed by SGPK and has the aim to digitize all existing data on *physical properties of rocks* exposed in Switzerland and surrounding regions. The ultimate goal of SAPHYR is to make these data accessible to public. The database of physical properties, derived from literature or systematically measured, are density (complete to about 80%) and porosity, seismic (Vp complete to about 80%, Vs complete to about 30%), magnetic, thermal properties, permeability and electrical properties. The potential use of the density and seismic information in level I and II would need some further assessment, but a possibility is to map the regional variability of the rock reference condition at depth in regional studies.

12.Other datasets

A considerable amount of information is available from the archives of other institutions, such as the Geotechnical institute of ETHZ and EPFL and the different Cantonal offices. The data are generally open, but mostly in paper format (e.g. borehole logs, reports on local geological and geophysical studies), which can introduce some limitation in the direct use. A first phase of digitization is nevertheless possible, depending on the available budget. To extract the significant information for the risk model would need a complete screening of the material. There is considerable risk that this information will be lost in coming years, when the target geotechnical research at ETHZ or EPFL is redefined, or when institutes are reorganized.

INSAR (Interferometric Synthetic Aperture Radar) data are commonly used to identify and map instable rock and soil slopes that slide due to gravitational forces. Very interesting for our purpose is the potential to identify areas with significant ground settlement typical observed for young sediment deposits. The usefulness of this technique would need further investigations.

Strategies for implementation

The primary goal for the risk model of Switzerland is to define a spatial layer of site-response amplification factors to be superposed on the ground motion or seismic hazard values defined on reference rock condition.

The layer should consist in the discretization of the national territory into sub-domains, corresponding to areas (classes) of similar geological, structural and geophysical characteristics, having similar seismic response. The site amplification factor for each sub-domain or class needs calibration with measurements. Additional sub-layers related to earthquake-induced phenomena could be considered as well (e.g. liquefaction, landslide). The calibration of the seismic amplification factors is however of first priority. We therefore provide an overview of possible strategies for the calibration of amplification factors for sub-domains or classes, and the practical implementation of a site-amplification layer for the use in risk analysis.

We propose an approach of consecutive phases of increasing model complexity, where zonation is progressively refined depending on the available data and the variability of the expected seismic site-response. Special attention has to be given to the separation of the aleatory variability of ground motion amplification at a particular site from the epistemic uncertainties related to the model uncertainty.

1. Zonation strategy

As previously discussed, a classification scheme simply based on surface geotechnical/geological information is not sufficient to depict the large variability of the site response. For this reason, separation between sub-domains of classes should be based on the comparative analysis of measured empirical amplifications, available Vs-profiles and calculated amplification functions using empirical relations, H/V curves, f_0 values to define the frequency band in which amplification occurs, existing geological/geotechnical information and topographic/morphologic data.

We expect to distinguish between at least four wider classes with potential for sub-classification and a special class including areas of potential earthquake-induced effects. The separation of classes, level of amplification and frequency bands at which they occur, need to be defined during the assessment and might require additional measurements to reduce epistemic uncertainties:

- **Hard rock sites (HR)**: rock is supposedly exposed and compact; a thin layer of weathered material might be present, but only affects ground motion at high frequencies above ~10Hz. Geometrical effects due to topography can be present in few cases, however with small amplification expected (<2). A sub-classification into different rock classes (e.g. metamorphic, sedimentary) might be envisaged.
- **Weathered rock sites and stiff soils (WR-1D):** site amplification might be present (>2) and can be described mostly by 1D site-response. Sub-classes might be defined by assessing layer thickness and/or f_0. A sub-classification taking into account the properties of underlying compact bedrock might be envisaged.
- **Soft sediment sites (SS-1D)**. Site amplification induced by site resonance is significant and can be described by 1D site response. Resonance occurs in the frequency range of buildings and structures. Sub-classes might be defined assessing soil composition, and layer thickness and/or f_0.
- **Complex soft sediment sites (SS-2D)**. Site amplification induced by site resonance is significant and cannot be described by 1D site-response. Resonance occurs in the frequency range of buildings and structures. Amplification is due to 2D/3D resonances, focusing of waves or edge generated surface waves. Sub-classes might be defined assessing soil composition, and layer thickness, geometry of the site and f_0.
- **Special cases with induced effects (IN)**; Sites that might show particular site-specific phenomena including liquefaction, ground settlement and triggered mass-movements. Areas in this class are also part of one of the above classes.

The best strategy is to analyze the ground motion variability by using observed empirical amplifications at seismic stations, and derived amplification from the collected Vs profiles using empirical relations. This will give us the possibility to establish classes by sorting the dataset according to the level of amplification, and to relate the outcome to existing surface geological/geotechnical information, topographic/morphologic data and other datasets available. This allows to calibrate average amplification factors for the classes, together with their epistemic uncertainties. Amplification factors for each class are preferably calibrated on Fourier spectra, and the response spectra amplification is subsequently computed from scenarios using the de-aggregation of the seismic hazard, Montecarlo sampling and random vibration theory.

The classes can be applied at national scale. The consideration of measured f_0 values or depth information is the consecutive step, with the aim of defining sub-classes if possible at national scale in the long-term, but certainly applicable in certain regions due to the density of H/V measurements available. Other sub-classification depends on the outcome of the proposed study.

Finally, results from microzonation studies could be applied at local scale and would replace the classes previously defined. This however is related to a long-term strategy and would require the compliance to a set of rules, the elaboration of intermediate results and the verification with earthquake recordings as defined in part 1 of this document.

2. Implementation steps

In order to be successful, we recommend the following steps (**tasks**) enumerated progressively. Background details to the steps are given in the comments (a) to (f) in the appendix:

1) Homogeneous assessment of the SED H/V database and integration of external data. Homogeneous derivation of f_0, H/V amplitude and directional properties. The amplitude at the H/V peak might be used to assess the velocity contrasts at depth (d), the directional features to derive 2D resonances (b). A classification scheme of the H/V curve shapes can be developed to define areas of similar site-response.
2) Include all Vs measurements available for Switzerland in the SED database, asses the quality of the analysis, and perform ambient vibration H/V measurements at these sites (if not yet available).
3) Homogenize the Japanese data; in particular, transform geologic logs into a geologic/geotechnical description and soil classification as applied in Switzerland. Even if ambient vibration recordings are not publically available today, an effort should be given to receive such data for a homogeneous derivation of f_0, H/V amplitude and directional properties.
4) Derive amplification from the collected Vs profiles using empirical relations. Compare with observed empirical amplification, when available, for validation.
5) Develop and derive potential proxies from topographic information (a, b).
6) Validate the available information collected so far in project GeoQuat and GeoMol (b, c). Test the available layer-thickness information available in project GeoQuat against f_0 values (c).
7) Validate the data available in project SAPHYR (d) by comparison to H/V curves and the tomographic seismic model used at SED for earthquake location; if useful add SAPHYR data to the geological information.
8) Validate possible applications of INSAR data to map soft sediments and areas prone to liquefaction and landslides; assess the availability of already existing processed data.
9) Combine all information and perform a stepwise analysis. Calibration and testing of proxies to derive classes and sub-classes with the related uncertainties (e).
10) Identify gaps in the dataset and perform additional measurements (H/V, Vs measurements, and temporary seismic stations for obtaining empirical amplifications).
11) Test implementation of location modifiers in the risk tool at national scale.

12) Validate the macroseismic amplification map with the available ground-motion amplification data by using ground-motion to intensity conversions. Investigate sites with significantly increased or reduced intensities during past earthquakes, and perform measurements (see 10).
13) Derive an alternative macroseismic amplification map from the ground-motion modifiers at national scale.

3. Special sites

Special cases (IN) with expected induced effects are defined to highlight particular site response features which cannot be represented using the proposed approach. Such cases will require further investigations. In a first step, the identified sites will be simply marked as special case, with a code indicating the possible phenomena to be expected.

This includes the following tasks:

14) Develop procedure to map fine-grained saturated sediments (very low velocities) with high chance of non-linear response, cyclic mobility, liquefaction and subsidence.
15) Develop procedure and map areas of possible landslides. Mapping of these special sites could be based on the integration of existing information from natural hazard maps, INSAR and local reports.

The identification of special sites strongly relies on the joint analysis of different site-specific sources of information. Integration of microzonation studies would be essential.

4. Verification

Before finalization, the site response model should undergo a phase of verification, in order to test the quality and reliability of the site-amplification factors defined for the classes. Verification is based on residual analysis with observations at sites in Switzerland, not be part of the initial calibration dataset. This might be new sites in areas of future microzonation studies, specific test areas, and sites of new seismic stations either permanent or temporary (6-12 months depending on the seismicity). Potential sites of interest are the large Swiss cities that have important exposure, but also densely populated sediment valleys (e.g. Aare, Ticino). Verification and implementation, and further developments of the location modifiers would require the following steps:

16) Perform measurements at sites (H/V, Vs measurements, and temporary seismic stations for obtaining empirical amplifications) and numerical ground motion simulation, possibly where project GeoQuat is presently improving the models. This serves to validate potential future combined analysis.
17) Validate sites of new seismic stations either permanent or temporary. Perform 6-12 months measurement campaign for verification at selected sites. Refine proposed location modifiers.
18) Develop long-term strategy to improve the location modifiers by including microzonation studies with analyzed earthquake recordings from temporary seismic stations, new Vs and H/V measurements, and numerical ground motion modeling.
19) Improve layers for the special cases (IN) adding models for the non-linear response that cause liquefaction and triggering of mass movements. The main target are probabilistic descriptions of the phenomena from large numbers of magnitude-distance scenarios that are covering the de-aggregation of the seismic hazard at different return periods.

5. Uncertainty evaluation

The proper treatment of uncertainties in the amplification factors for all classes is a fundamental step. To fully explore it, also the uncertainties related to the different sources of information (e.g. velocity profiles, surface geology, f_0 estimates) used for the calibration has to be assessed, and the mechanism of propagation of such uncertainties understood. As well, the necessary generalization induced by the use of simplified surface proxies and simplified classification methods introduces an additional epistemic uncertainty that has to be properly quantified, and whenever possible reduced.

Assessing and isolating the different contributions to uncertainty is nevertheless not an easy task. Some datasets do not provide any direct form of confidence bounds or, on the opposite, are not complete enough to cover the possible range. This is the case of the geological/geotechnical mapping and, to some extent, to the limited number of sites in measurements database. As well, the error related to the classification procedure is difficult to quantify directly. In all these cases, related uncertainties have to be treated as epistemic and special techniques of assessment are to be developed (f). The installation of temporary seismic stations to derive empirical amplifications is the only way to verify estimated epistemic uncertainties of the soil-class amplification functions.

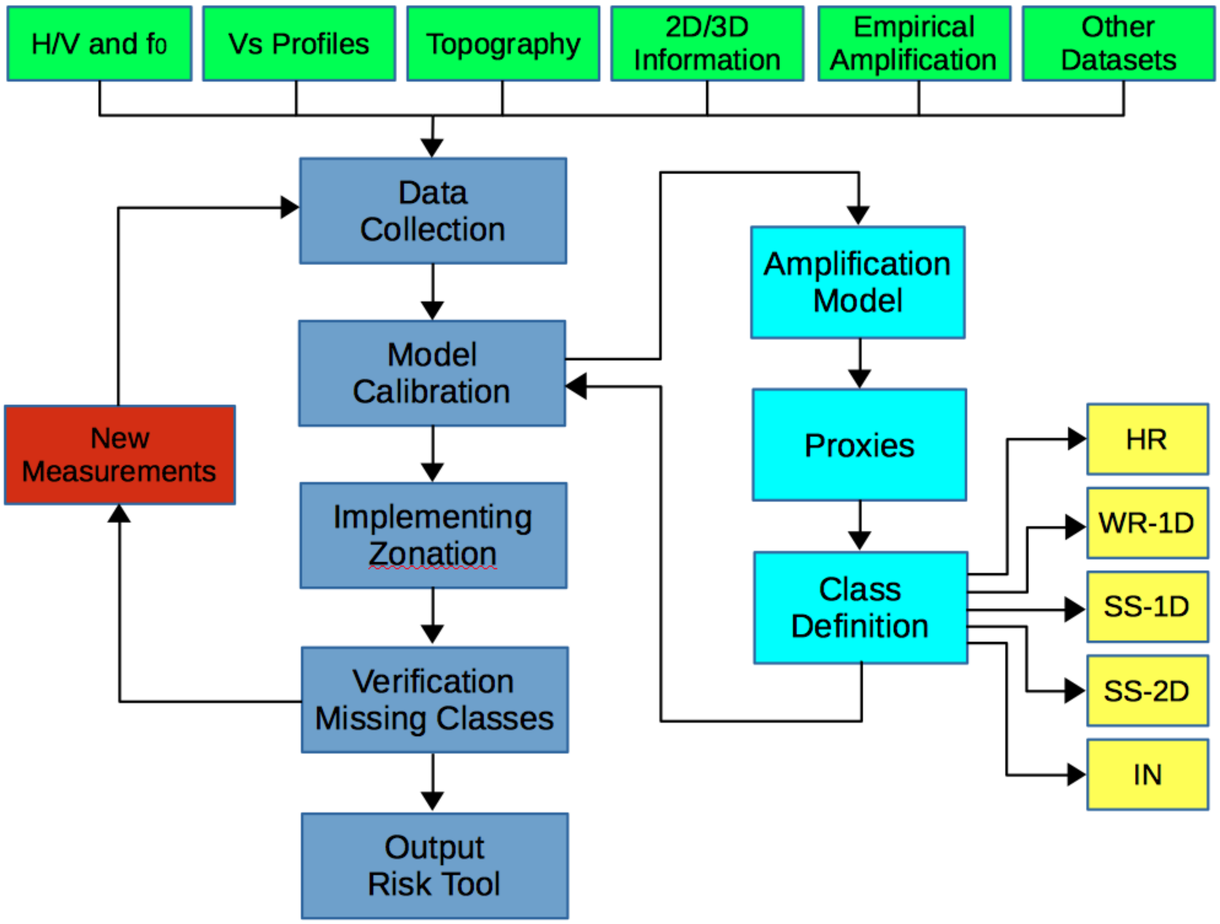


Figure 8, *Diagram showing the workflow for the implementation of a national scale site amplification model in Switzerland.*

Conclusions

In this document, we analyzed and proposed strategies for the implementation of a layer of location modifiers to be used in risk tools. The proposed scheme relies on the combined use of existing and newly developed proxies, calibrated on multiple datasets available to SED and on observed and estimated ground motion amplifications. In light of the present level of knowledge, the most recent scientific developments in the field, and the quality and reliability of these datasets, the proposed strategy appears feasible in a realistic time. Implementation of a location modifier in risk tools is straightforward for any parameter needed as long as the software allows changes to include the site response.

The work includes an initial scientific phase, where datasets need to be homogenized, analyzed and new proxies established and tested. The second phase concerns the definition of the amplification factors and the related uncertainties, followed by a more technical phase of implementation at national scale. These tasks require the collaborative work of two researchers, focused on the improvement of the database, the development of proxies, and ground-motion statistical analysis and subsequent uncertainty assessment. Complementary, field measurements for site characterization and ground motion modeling needs to be performed as well. The last phase includes the validation and improvement through local studies, and the development of a long-term sustainable strategy.

The proposed strategy is a mid-term four-year project with an extension of one or more years to transform it into a long-term process. The expected timetable is summarized in table 2. The overlapping between tasks is necessary to allow a possible review of results. The related costs for work force are provided in table 3. Field costs, instrument costs, and spare parts and total costs are given in table 4. Not covered in this work plan are the digitization of geotechnical information on paper, available at geotechnical institutes at ETHZ and EPLF or elsewhere.

Tasks	Year 1		Year 2		Year 3		Year 4		Year 5..	
(1) Homogeneous H/ V database and analysis										
(1) Assess H/V shape as proxy										
(2) Include Vs measurements in database										
(3) Homogenize Japanese data										
(4) Derive amplification from Vs profiles										
(5) Develop proxies from topography										
(6) Analyze data from GeoQuat and GeoMol										
(7) Validate use of SAPHYR data										
(8) Validate use of INSAR data										
(9) Define classes and sub-classes										
(10) Identify gaps and perform measurements										
(11) Test implementation in risk tool										
(12) Validate macroseismic amplification map										
(13) Revise macroseismic amplification map										
(14) Develop procedure to map liquefaction										
(15) Develop prodecure to map landslides										
(16) Combine GeoQuad with local study										
(17) Validation and refinement										
(18) Include microzonation, long-term strategy										
(19) Improve information for special cases										

Table 2: *Proposed timetable for the implementation of the site-response layer for the risk model.*

Description	Year 1		Year 2		Year 3		Year 4		Year 5..	
Senior scientist (130)	6	6	6	6	6	6	6	6	6	6
PostDoc (110)		6	6	6	6	6	6	6	6	
IT database (110)	1	1	1	1		1		1		1
Support and technicians (90)	3	3	3	1	1	2	2	1	1	
Cost for work force per year	**249 kCHF**		**289 kCHF**		**272kCHF**		**272 kCHF**		**202 kCHF**	

Table 3: *Estimate of required work force in each time block (person-month) and related cost. The costs do not include overheads of 10%.*

Description	Year 1	Year 2	Year 3	Year 4	Year 5..
Travel and field costs	5 kCHF	15 kCHF	20 kCHF	20 kCHF	10 kCHF
Instrument costs (A)		20 kCHF	40 kCHF	40 kCHF	10 kCHF
Spare parts and material		5 kCHF	5 kCHF	5 kCHF	5 kCHF
Cost for work force	249 kCHF	289 kCHF	272 kCHF	272 kCHF	202 kCHF
Total costs per year (B)	**254 kCHF**	**329 kCHF**	**337 kCHF**	**337 kCHF**	**227 kCHF**

Table 4: *Estimate of travel and field costs, instrument costs and spare parts, cost for work force and total costs. The costs do not include overheads of 10%. (A) Alternative long-term concepts should consider a pool of instruments for microzonation studies. (B) Not included are possible costs for external datasets related to tasks (3), (6) and (8).*

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Appendix

a) Information contained in topographic features:
   - Loose sediments preferentially settle in low-energy depositional conditions, which are mostly related to low altitudes (relative to minimum and maximum value of the local drainage system). Conversely, coarse soils are more typical of high-energy conditions and high (relative) altitudes.
   - Sediment-specific surface morphology proxies (e.g. roughness, texture) might be combined to geometrical features (e.g. maximum bedrock depth, basin width and distance from basin edges) or might help to separate rock sites from sediment sites.

b) Validate the properties of sedimentary basins related to 2D/3D wave phenomena, and compare it with ground motion observations. Properties are the bedrock geometry, the shape ratio of the basin, basin surface morphology (e.g. basin elongation, maximum width, average convexity) and location of the sites inside the basin (e.g. distance from basin edge). Directional H/V ratios in the basin might indicate 2D/3D resonances.

c) Information of layer thickness might be used to estimate f_0 or interpolate measured values of f_0 in relatively homogeneous areas.

d) There might be regional differences in empirical amplifications due to the properties of the rock at depth, in particular when seismic bedrock is not equivalent to the geologically defined rock (e.g. in the Rhinegraben at Basel). The differences in velocity contrast at depth due to the properties of the bedrock might be related to the effectiveness of the resonances in sediments; the amplitude at the H/V peak might be used to assess such velocity contrasts at depth.

e) Output amplification factors (in either Fourier or response spectra) should be anelastic and uniformly referenced to the Swiss rock reference profile. The attenuation models could be calibrated in term of average kappa for each soil class. Other types of output are also possible, depending on the requirements of the risk modelers, such as average V/H spectral conversion factors and duration models; such additional parameters would certainly be a valuable piece of information in case that stochastic simulation is performed site-specific.

f) We might apply statistical approaches based on *bootstrapping*, where the uncertainty on site-amplification factors can be obtained by direct sampling of sub-populations of the input parameter space. Such approach allows inferring intrinsic variability within and between ground classes, the sensitivity to the different proxies and to their combined use, and the effect of the model complexity by progressively adding information.