SERA
Seismology and Earthquake Engineering
Research Infrastructure Alliance for Europe

DELIVERABLE

D7.2 - Best practice and quality assessment guidelines for site characterization

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Summary

Main objective of this deliverable is to provide recommendations for homogenizing the information of seismic site characterization at European strong motion sites, as resulting from the efforts of Task 7.2 in Network Activity #5 of the "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe – SERA" project (Project no. 730900, funded by the Horison2020 INFRAIA-01-2016-2017 Programme). This document first describes the outcomes of an international questionnaire dedicated to define the most relevant site characterization indicators. Next, it provides guidelines at European level to homogenize and to define an overall quality metrics for site characterization information.

Specifically, we define a list of indicators considered as mandatory for a reliable site characterization. We then propose a summary report containing the most significant background information for assessing the quality of each significant indicator. The quality metrics strategy is aimed at evaluating in a quantitative way the overall quality for a site characterization analysis.

A draft version of these guidelines have been presented and discussed during an international SERA workshop held in L'Aquila (Italy) in March 2019 (https://sites.google.com/view/site-characterization-workshop/home), and the present version takes into account the feedback from these discussions. This is the first attempt to move forward to reach high-level metadata for site characterization and the present proposition can be improved and modified after a few years of experience and feedback from users.

1 Introduction

Seismic site characterization of rock and soil properties is a need shared by various applications in seismology and geotechnical engineering, such as: (i) the site response at seismic stations and the calibration of strong-motion records for the estimation of attenuation relationships (GMPE), (ii) the evaluation of local site amplifications for realistic shaking estimates and for site-specific hazard assessment for critical infrastructures, and (iii) the soil classification for building code applications.

In the last years, several efforts have been carried out at national and international levels to define standards and guidelines for single parameters related to the seismic site characterization (e.g., Foti et al., 2018; Hunter and Crow (ed.), 2012; SESAME Deliverable D23.12, 2004; Consortium of Organizations for Strong Motion Observation Systems, http://www.cosmos-eq.org). However, there is not yet a common way to exchange site characterization information, whereas setting-up standard practices for a comprehensive seismic characterization of a site, together with a clear evaluation of their quality, are becoming very important to reach high-level metadata for site characterization.

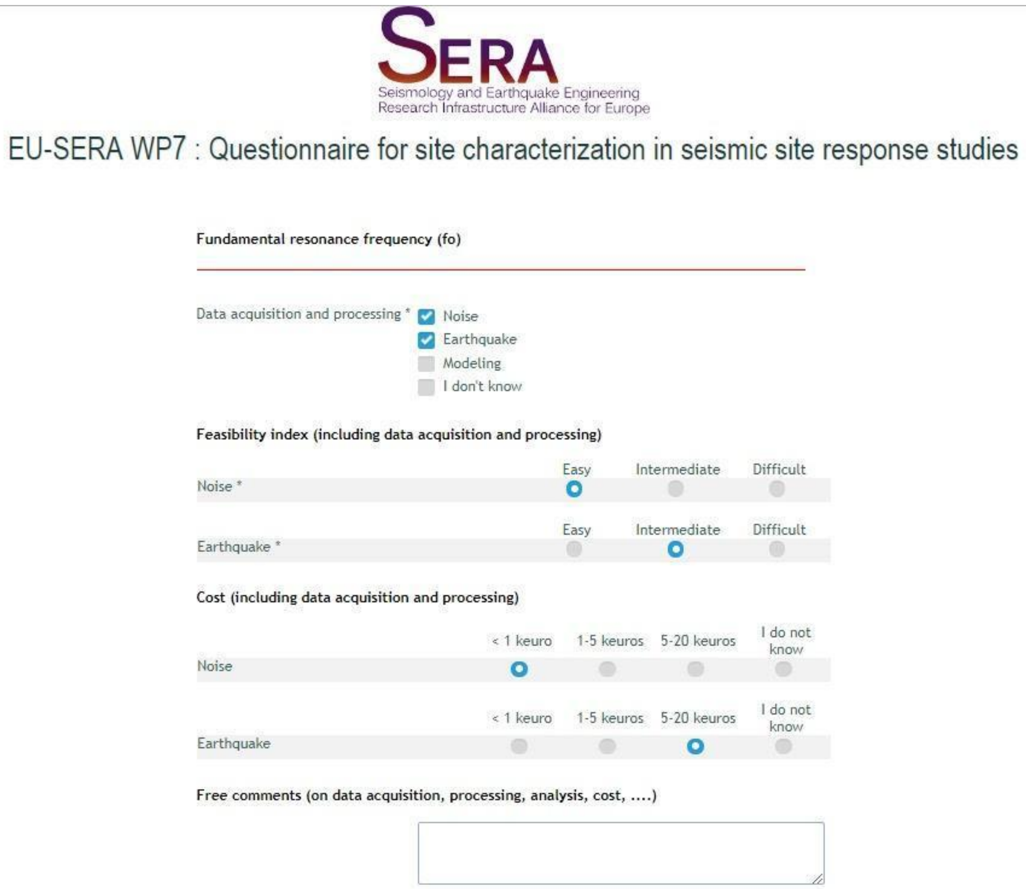
Within this context, the 2017-2020 activities of the "Networking databases of site and station characterization" (WP7-NA5 of the SERA "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe" Horizon 2020 Project) aim at proposing a reliable and efficient European framework for site characterization, in close connection with actual and future requirements of seismic hazard and risk stakeholders (seismic network operators, earthquake seismologists and engineers, Eurocode 8).

More specifically, the Task 7.2 ("Best practice and site characterization quality assessment") was devoted to the definition of the necessary information for a reliable seismic site characterization analysis, and to propose an "objective" assessment of the quality of site metadata through a specific metrics. These activities were particularly addressed to improve the site metadata at the seismic stations of all permanent networks, in the Euro-Mediterranean area which appear to be highly heterogeneous if not completely absent.

The task has been divided in three parts: (i) the evaluation of the most relevant site effects indicators; (ii) the definition of a quality metrics on the site characterization parameters and (iii) the proposition of guidelines for a standardized reporting of the information on site indicators.

As a first step, we have prepared a Questionnaire for collecting existing bibliography and best practice schemes to compute indicators for site effects characterization. We sent the Questionnaire to selected research groups of different countries, both partners of the SERA project (ISTERRE-CNRS, France; ETH, Switzerland; INGV, Italy; AUTH, Greece) and several external groups involved in site characterization (Caltech-USGS, USA; AFAD, Turkey; Virginia Tech USA; GFZ, Germany; ITSAK, Greece; University of Potsdam, Germany; UoT-University of Texas, USA; INGV, Italy), and collected back the answers. Each team provided the list of site-effects indicators, their importance for site effects assessment (based on expert judgment) and the preferred methods of analysis for retrieving them. The scientific community working on site characterization is using several site-effect indicators that can be grouped into (i) Scalar parameters (e.g. V_{S30} or resonance frequency), (ii) Depth-dependent profiles (e.g. shear-wave Vs profile), (iii) Frequency-dependent curves (e.g. spectral ratio), (iv) Geological/Morphological descriptors (e.g. Surface geology/lithology unit) and (v) Advanced indicators (e.g. 2D or 3D aggravation factors, topographic amplification). The analysis of the Questionnaire revealed a consensus on several basic indicators (such as the resonance frequency, V_{S30} or the 1D Vs profile), together with a few key open issues related to the lack of standards on data acquisition, analysis methods and metrics, and to the scarce awareness of the quantitative evaluation of the uncertainty in the measurement results. The list of indicators and the associated bibliography can be found in Appendix A.

The first Questionnaire allowed setting a fixed list of indicators for which we then asked to a broader audience, using an improved online Questionnaire (Fig. 1.1), to indicate for each indicator a) the best method of estimation, b) the level of difficulty for compute it and c) the approximate cost for deriving it. Finally, we asked to rank the selected indicators according to a priority scale (e.g. mandatory, recommended or optional indicator).



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EU-SERA WP7 : Questionnaire for site characterization in seismic site response studies

Fundamental resonance frequency (fo)

Data acquisition and processing * ☑ Noise ☑ Earthquake ☐ Modeling ☐ I don't know

Feasibility index (including data acquisition and processing)

	Easy	Intermediate	Difficult
Noise *	◉	○	○
Earthquake *	○	◉	○

Cost (including data acquisition and processing)

	< 1 keuro	1-5 keuros	5-20 keuros	I do not know
Noise	◉	○	○	○
Earthquake	○	○	◉	○

Free comments (on data acquisition, processing, analysis, cost, ...)

Figure 1.1: Online Questionnaire on Fundamental resonance frequency (f0)

Seventy one teams or researchers, out of about 300 colleagues receiving a request of participation, contributed to this second phase, coming from different countries (69% Europe, 31% other countries; Fig. 1.2).

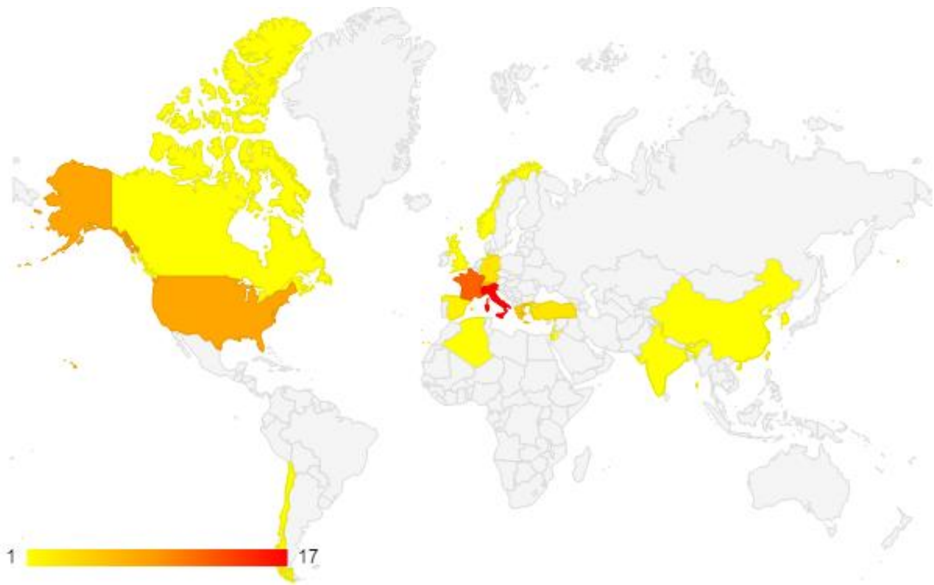

Figure 1.2: Countries contributing to the online Questionnaire: colors are proportional to the number of researchers.

Although the mailing list of the invitation to fill the questionnaire was designed to homogeneous sample the various communities of different scientific fields (seismology, engineering, geotechnics, etc.; Fig. 1.3), the actual answers were somewhat unbalanced because of a lack of feedback mainly from the civil engineering community.

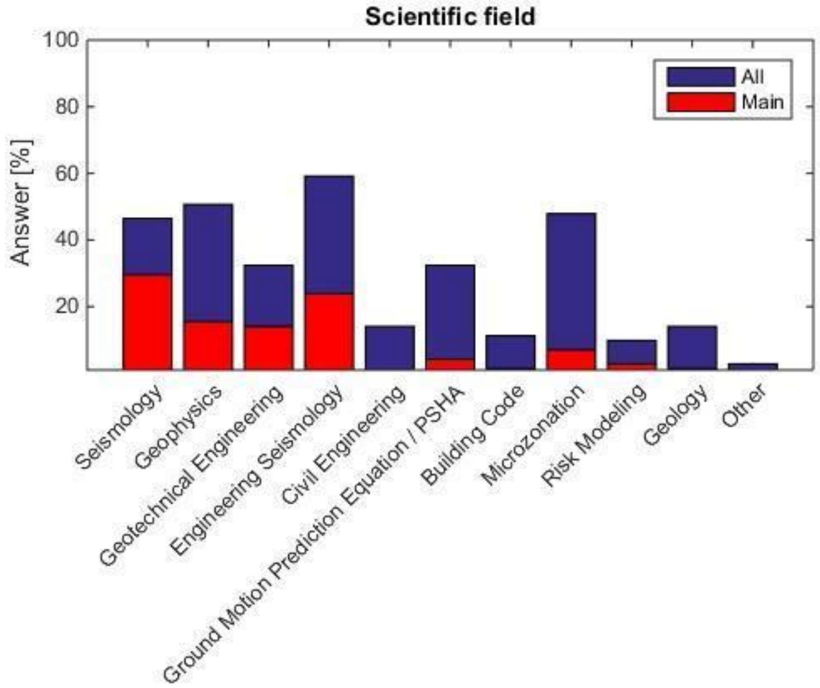

Figure 1.3: Scientific fields declared by the online Questionnaire participants. Each researcher could indicate more than one field (blue) and the main field he/she feel to belong to (red).

The analysis of the results was the basis of the presentation of the standard best-practice, the proposition of a quality metrics and the strategy for improvement of site condition metadata that are discussed in these guidelines.

A draft version of these guidelines has been presented and discussed during an international SERA workshop held in L'Aquila (Italy) in March 2019 (11-12th of March, https://sites.google.com/view/site-characterization-workshop/home). The present version takes into account the feedback from these discussions. Despite of the agreement on the principle to have such a guideline on site effect indicators and related quality metrics, not always there was a consensus on the very details: this is a proposition to move forward and fill the existing gap, but there could be adjustments after a few years of practice.

2 Indicators for site effect characterization

The site-effect indicators, which were submitted to the scientific community working on site characterization through the online Questionnaire, are listed in Table 2.1. They can also be grouped into (i) Scalar parameters (e.g., V_{S30} or resonance frequency), (ii) Depth-dependent profiles (e.g. shear-wave Vs profile), (iii) Frequency-dependent curves (e.g. spectral ratio or dispersion curve), (iv) Geological/Morphological descriptors (e.g. Surface geology/lithology unit) and (v) Advanced indicators (e.g. aggravation factors for 2D or 3D valleys, surface topography effects). See Appendix A for the reference bibliography related to the indicators and methodologies used in seismic characterization analysis.

Table 2.1 - Description of site-effect indicators mentioned in the online Questionnaire

Parameter	Description	Group
f0	fundamental resonance frequency	i
f0, f1, ….fn	frequency peaks of higher modes	i
A0, A1,.......A_N	Amplitude of the spectral peaks at the resonance frequencies (i.e. amplitude from spectral ratio HVSR and HVnoise or amplification from standard spectral ratio SSR)	i
Site Transfer Function (STF)	Curve in the frequency domain describing the site amplification function at a site	iii
Preferential direction of ground motion	Predominant direction of ground motion (for example computed by particle motions; rotated spectra; ellipticity vector by covariance matrix method; and/or time-frequency polarization analysis)	iii
Duration Lengthening	frequency-dependent lengthening of seismic ground-motion duration	iii, v
kappa0	high-frequency near-surface attenuation factor	i
Frequency-dependent attenuation (FDA)	model for near-surface attenuation (k), Quality factor (Q) or damping as a function of frequency	ii
V_{S30}	The time-averaged shear-wave velocity Vs in the first 30 m of depth (following NEHRP and EC8, it is defined as travel time average in the uppermost 30m)	i
Vsz_below_30m Vsz_above_30m	travel time-average of Vs at a fixed depth below or above 30 m (z=5m, 10m, 20m, etc.)	i
Vs_seismic_bedrock(*)	Vs of the seismological bedrock	i
H_seismic_bedrock(*)	depth of the seismological bedrock	i
H_engineering_bedrock	Depth of the engineering bedrock (e.g. defined as corresponding to Vs=800 m/s for EC8)	i
Vs(z)	Subsoil velocity profile of shear-wave (Vs) as a function of the depth (z)	ii
Vp(z)	Subsoil velocity profile of compression wave (Vp) as a function of the depth (z)	ii
dispersion curve	surface-wave dispersion curve; apparent phase-velocity or slowness as a function of frequency for Rayleigh or Love waves	iii
Rayleigh wave ellipticity	Rayleigh wave ellipticity curve	iii
Building code Site Class (soil class)	Soil (site) class according to a specific Seismic Building Code (e.g. EC8, NEHRP...)	i

Aggravation factor for basin and topography	Ratio between 2D (or 3D or recorded motion) and 1D estimates for a given ground motion intensity measure: may be either a scalar (if it applies to a scalar IM, e.g., PGA or Arias intensity), or frequency dependent (e.g. for STF, or amplification factor on response spectra)	i, iii, v
Surface geology	Geological/lithological information from available cartography (geological & thematic) and geological surveys	iv
Topographic factor	Different interval values of slope and morphologic elements (landform), following Building Seismic Code provisions to compute the topographic code	i, iv
Geometrical parameter	any parameter related with 2D or 3D structure (surface topography or underground lithological heterogeneity)	i, iv
geo-stratigraphic 1D log model	stratigraphic column with geological unit description	ii, iv
H_water_table	depth of the water table	i
Non-linear degradation curves	Curves characterizing the change of mechanical properties with shear strain (γ), in terms of normalized stiffness modulus (G/G0, where G0 is the small strain modulus), damping ratio (D), and/or excess pore pressure ratio (Ru = Δu/p', where Δu is the excess pore pressure and p' is the mean normal effective stress).	ii
Geotechnical parameter	geophysical and geotechnical parameters; e.g. SPT, CPT, qu, Plasticity Index, CRR....: CPTU Piezocone test DMT Flat dilatometer test SPT Standard penetration test DPSH Dynamic probing super heavy test VT Vane test SLAB Static laboratory test ET Electrical tomography TDEM Time domain electromagnetic method	ii

(*) there is no consensus on the meaning of the expression "seismological bedrock" (see chapter 3.5)

Following the results of the Questionnaire, 87% of researchers agreed on the list completeness. The 13% of them, however, indicated that some parameters were missing, such as:

- indicator on dependence of the site response to the earthquake location (back-azimuth, distance and depth);
- indicator on 1D/2D/3D behavior: it is important to verify whether the site can be idealized using a 1D model (i.e. a stack of homogeneous layers overlying the bedrock) or 2D/3D model, meaning that the lateral variability of geological formations affect the seismic behavior;
- indicator on soil-structure interaction (mainly for strong motion stations installed in, or near to, a building).

Other issues are related to the unclear definition of some indicator (e.g. not-unique interpretation of seismic bedrock) and to the difficulty of studying the seismic behaviour of rock sites. Last but not least, attention was drawn on the importance of providing the uncertainties accompanying each value, wherever available, to show the confidence we have in that particular parameter's value for that particular location; unfortunately, this issue is often neglected, leading to very heterogeneous site metadata, which is most often overlooked by down-stream users of waveform data, and may lead to biased, or oversold - if not wrong - results.

Following the ranking of the selected indicators performed by the Questionnaire participants, the indicators have been sorted according to the different degree of importance for contributing to the site characterization (e.g. mandatory, recommended or optional; Fig 2.1).

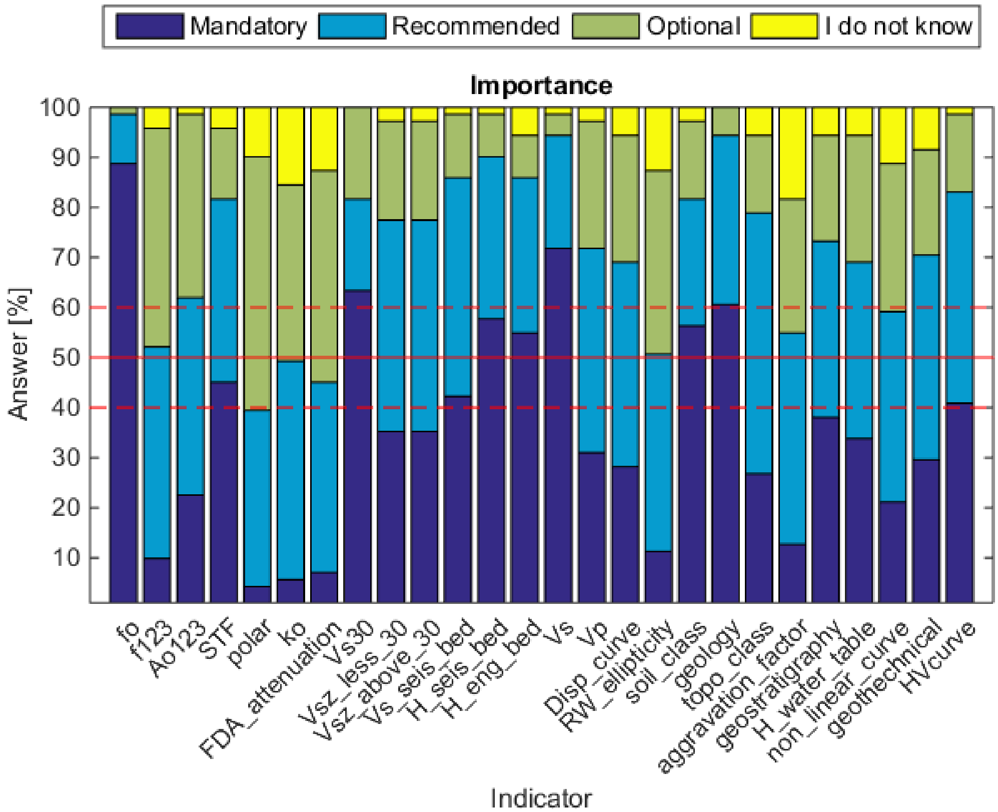

Figure 2.1: Answers of participants to the questionnaire assessing the different degree of importance of the indicators.

According to the Questionnaire results, almost all indicators were considered to be "recommended" for a reliable site characterization by the majority of participants, whereas only a few of them were considered as "mandatory" (Table 2.2).

Table 2.2: List of indicators whose percentage of "mandatory" answers exceeds 40% (percentage is related to the Questionnaire answers).

Indicator	Mandatory
F_0	>80%
V_s(z)	>60%
V_{s30}	>60%
Surface geology	>60%
Depth seismic bedrock	>50%
Depth engineering bedrock	>50%
Soil class	>50%
Site Transfer Function	>40%
Vs seismic bedrock	>40%
HV curve	>40%

3 Indicator description

In the following we thus focus on the parameters considered as mandatory by the majority of the involved scientific community. Based on Table 2.2, we decided to select the indicators having a consensus greater than 50%: f_0, $V_S(z)$, V_{S30}, Depth of seismological and engineering bedrock, Surface geology, Soil class. For each indicator, we describe:

- the data type, data acquisition and processing techniques to derive it, together with the feasibility of its evaluation and the estimated cost (from the questionnaire results);
- the proposition of a template for the description of data acquisition and processing details.

In the best case, the value of an indicator, referred to a site characterization study, is supplied with a thorough description of the data acquisition and methods and the detail of the processing (complete full report). Some examples of complete report for different geophysical measurements can be found for station IV.ROM9 report (2018) and SED-AIGLE report (2019). An example of a complete geological report is IT. PTV-PONTEVICO report (2018).

On the opposite, there are cases where only a value is available, without any information on the data, processing techniques and uncertainties. Both situations can be found in seismic network databases. There is then a need to associate the reported value of the indicators with some standard information; this is necessary to attribute a quality assessment to the indicator inferred for a specific site.

The template proposed in these Guidelines represents the report intermediate between the two extreme cases, having the minimum background information for assessing the quality of the results of a computed indicator at a specific site. It is not intended to replace a complete site characterization report, which may follow other much more specific guidelines, but simply to offer a handy framework to homogenize information especially for seismic network metadata, and to allow an assessment of their quality as objective as possible.

The general structure of the intermediate report that should be associated to the provided indicator is summarized in Table 3.1. It contains 4 main sections: the first one with general information, the last one with the resulting value of the indicator including uncertainty estimation and, in between, the description of the main parameters of the data acquisition and analysis.

The template for each selected mandatory indicator is reported in Appendix B.

Table 3.1 - General structure for the intermediate report

SECTION	CONTENT
GENERAL	Authors Contacts Link to reports, papers, etc Coordinates of the site
DATA ACQUISITION	Date of experiment Location Equipment Instrumental setting
DATA ANALYSIS (PROCESSING METHODS AND PARAMETERS)	Methodology and general processing parameters Results Uncertainties and limits of resolution
RESULT	Average estimate and standard deviation

3.1 Fundamental resonance frequency, f_0

The survey indicated two main methods to obtain the fundamental resonance frequency (f0): one using ambient vibration measurements and the other from earthquake recordings (Fig 3.1). Some teams do propose to obtain f_0 from numerical simulation, but as a) they are not so numerous (less than 30%, see Figure 3.1) and b) such models are based on other site information (e.g. velocity profile), we decided not to take it into consideration.

According to the Questionnaire results, the easiest way to compute it is from noise measurements, with an indicative cost of less than 1 keuro (actually, it also turns out to be the easiest technique amongst all those listed to derive one of the seven "mandatory" indicators, see Figures 3.2 to 3.6); they should be performed in a relatively wide area, in order to provide useful information about the general setting of the site without any large impact on costs. However, the interpretation of the noise results is not always straightforward (e.g. Uebayashi, 2003; Mucciarelli et al., 2005; Bonnefoy-Claudet et al., 2009; Özalaybey et al., 2011; Uebayashi, 2003; Molnar et al., 2018).

The reliability increases if earthquake data are used, because they display the site behavior under the ground motion shaking (e.g. Haghshenas et al., 2008; Pilz et al., 2011; Cultrera et al., 2014). However, for earthquake data acquisition in areas of low-seismicity, there could not be enough data over a reasonable time period of the experiment, making it more expensive.

The template of the intermediate report of f_0 is in Appendix B.

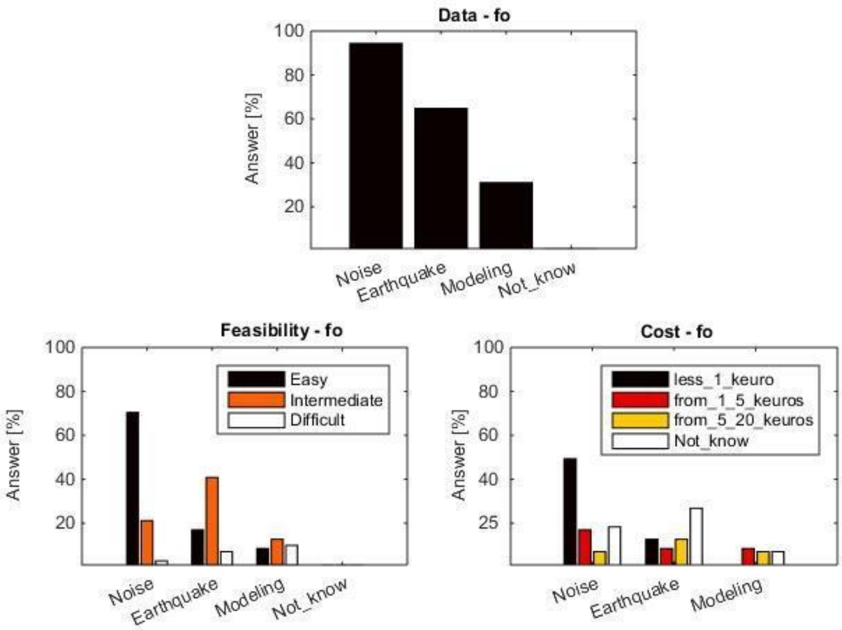

Figure 3.1: Type of data, feasibility and cost for f0 estimation from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment.

3.2 S-wave velocity profile, Vs(z)

Two main classes of methods are recommended to obtain the subsoil velocity profile of shear-wave (V_S) as a function of the depth (z), according to either non-invasive (active and/or passive seismic methods) or invasive (measurement in boreholes) measurements (Fig 3.2).

According to the Questionnaire results, the non-invasive methods seem to be more and more widely used compared to the invasive ones, probably because of their cost, which is generally considered lower. It however spans the whole range 1 - 20 k€, probably depending on the site configuration and thickness. The feasibility index and cost of using invasive methods is also highly variable, as it strongly depends on investigation depth and on local geological conditions.

A common source of error is related to the investigation depth, as some investigators erroneously provide velocity values at deeper depths than it is allowed by the data they have collected (e.g. for surface-wave methods, the depth of investigation should be limited to some fraction of the maximum wavelength measured, which is always a function of the sensor array aperture). Finally, V_s profile measurements at a rocky site should be performed with special care.

The template of the intermediate report of V_s profile is in Appendix B.

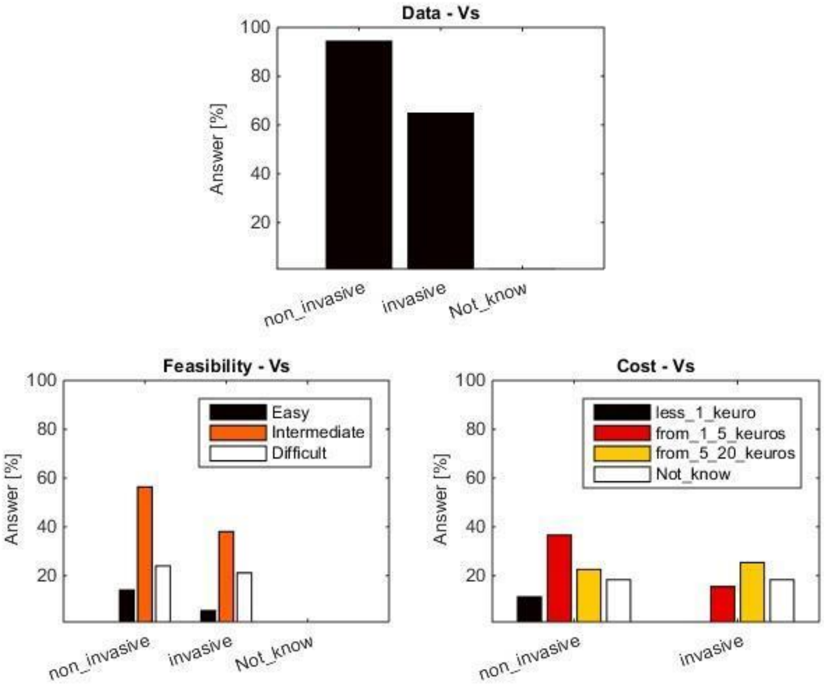

Figure 3.2: Type of data, feasibility and cost for $V_S(z)$ estimation from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment.

3.3 Time-averaged S-wave velocity in the upper 30 m (V_{S30})

The NA5 survey indicates five main methods to obtain the time-averaged shear-wave velocity profile at 30m (V_{S30}): two of them use in-situ Geophysical or Geotechnical measurements, and the others obtain inferred values from correlations with other kinds of information (Digital Elevation Model, DEM; Geology; Hybrid models, e.g. geology-slope or geomorphic terrain-based proxy; Fig 3.3). However, these methods cannot be considered as equivalent: Figure 3.3 indicates that direct measurements (using geophysical or geotechnical methods) should be preferred with respect to the inferred proxies. The geophysical and geotechnical methods are thus more widely recommended than the ones from proxies, though they are more expensive.

In general, non-invasive geophysical measurements represent an average condition for the site, whereas invasive or geotechnical measurements are punctual and usually shallow. On the other hand, estimation from secondary information (i.e. proxy models) using slope, geology, and geotechnical information is easier in implementation, but may result in significant biases and much larger uncertainties in V_{S30}.

The template of the intermediate report of V_{S30} is in Appendix B.

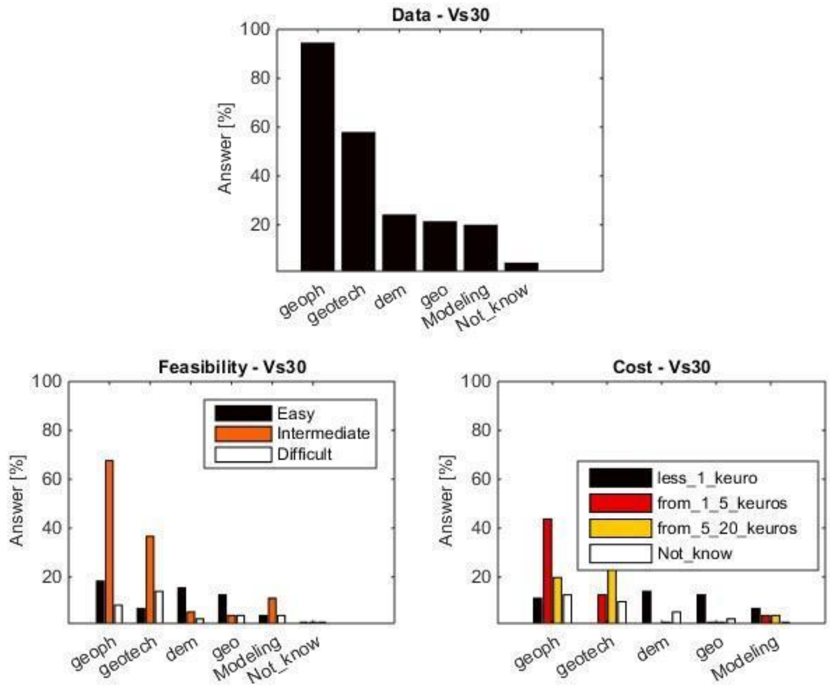

Fig 3.3 - Type of data, feasibility and cost for V_{S30} estimation from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment.

3.4 Surface geology

Surface geology can be inferred through available cartography (geological, lithological, etc.) or specific geological field surveys (Fig 3.4). The use of already existing cartography is easier and less expensive than field survey, though often less accurate because of the lower resolution of generally available geological information.

The accuracy of the geological description depends on the cartography resolution and profiles, as geological cross-section and stratigraphic sequence (if available) can be used to infer a preliminary model representative of an area.

The template of the intermediate report of surface geology is in Appendix B.

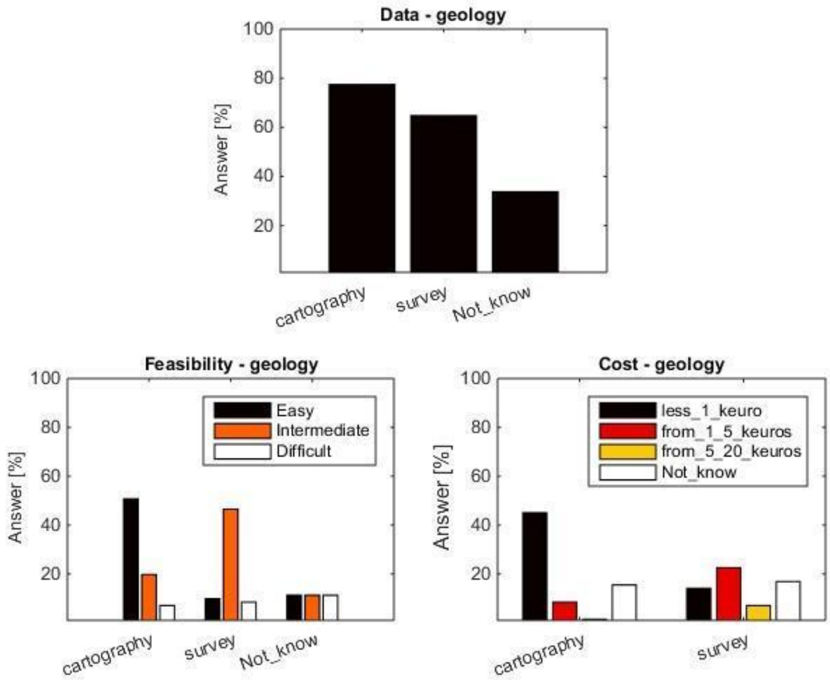

Figure 3.4: Type of data, feasibility and cost for Geology estimation from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment.

3.5 Depth of bedrock

The survey indicated that there is no consensus on the understanding of what is “bedrock”, and therefore on the corresponding depth. We thus considered two main different definitions:

- "Seismological" bedrock corresponds to the geological unit that, because of the impedance contrast with the upper layers, controls the lowest (fundamental) resonance frequency peak (f_0; Fig. 3.5); note however that some scientists consider the seismological bedrock as the crustal unit where the S-wave velocity is reaching a "crustal" value between 3.5 and 4.0 km/s.
- “Engineering” bedrock corresponds to the unit where a conventional Vs value is first exceeded. This conventional value may vary from one country or practice or code to another and must clearly stated in the report (typical values are 760 m/s, 800 m/s or 1500 m/s).

We identified two main methods to infer the bedrock depths: Non Invasive (active and/or passive seismic methods) and Invasive (measurement in boreholes).

According to the Questionnaire’s answers, non-invasive measurements seem to be more widely used than the invasive ones, and they are considered as less expensive. Moreover, the cost of invasive methods is strongly dependent on bedrock depth. In general, a deep bedrock depth is difficult to obtain and in these cases complementary geophysical and geological studies could be required to constrain it.

The comparison of Figure 3.5 with Figures 3.1 to 3.6 also indicates that seismological bedrock depth is considered as the most difficult to get amongst all site indicators.

The template of the intermediate report of bedrock's depth is in Appendix B.

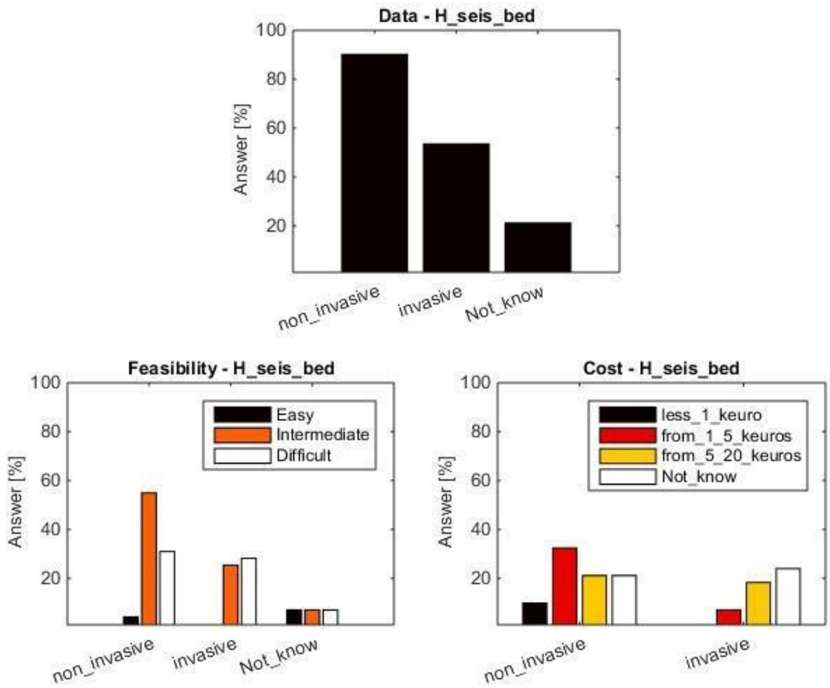

Fig 3.5 - Type of data, feasibility and cost for the estimation of Seismic Bedrock Depth from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment. Histograms for engineering bedrock are not reported because they are equal to the seismological bedrock results.

3.6 Building-Code Site class (soil class)

Four main methods are available to derive the Building-Code Site Class (alias Ground Type, in Eurocode 8, or Soil Class in some national building codes): Geophysical measurements, Geotechnical measurements, DEM (Digital Elevation Model) and Geology. As shown in Figure 3.6, there are far from being considered equivalent in terms of reliability; the geophysical and geotechnical methods are more widely recommended than the ones from DEM and geology, though they are more expensive and of more difficult feasibility (Fig. 3.6).

In the current practice, mostly V_{S30} or geological description are considered to obtain the site classification following the seismic code prescription. This makes the soil class indicator non-independent from some of the other mandatory indicators.

The template of the intermediate report of Soil class is in Appendix B.

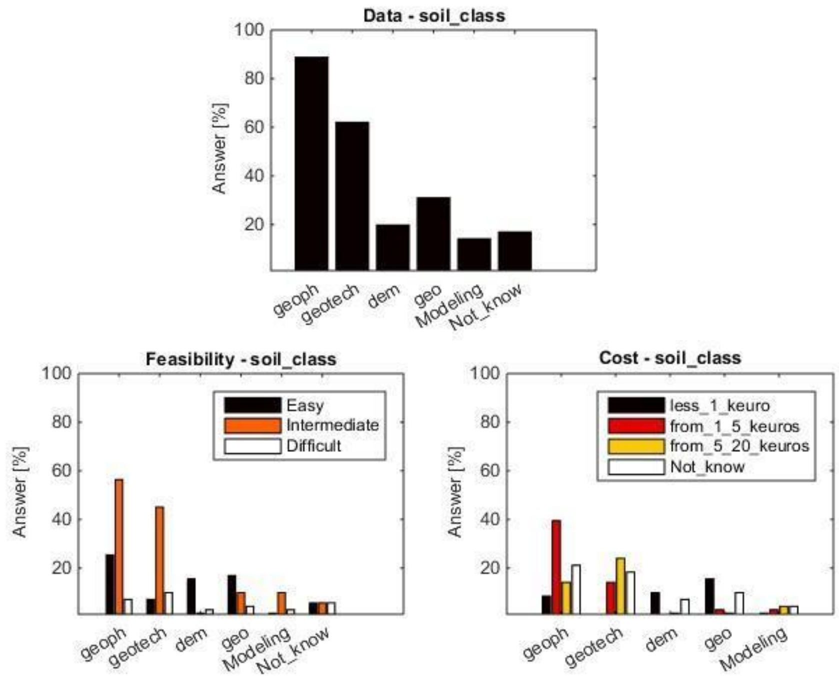

Fig 3.6 - Type of data, feasibility and cost for the estimation of Soil Class from Questionnaire results. Cost estimates do not include equipment cost: it is only the amount required to perform the measurements and interpret the results, assuming that the contractor already has appropriate equipment.

4 Quality metrics

4.1 State of the art

The overall quality metrics generally depends on the number and quality of information that can be recovered at a target site, and a site characterization study is considered more reliable when a larger number of surveys is available for one target site. However, even though some important good-practice guidelines or reference papers exist for a given single indicator (e.g., resonance frequency, surface waves based-methods, cross-hole and down-hole methods; e.g. ASTM D4428M-00, 2000; ASTM D7400M-08, 2008; Socco and Strobbia, 2004; Bard et al., 2010; Hunter and Crow, 2012; Foti et al., 2018; Molnar et al., 2018; see Appendix A for further bibliography), standardized procedures to qualify and quantify overall quality of site characterization information at a given strong motion site are missing at European and even world scales.

Indeed, it is not always easy to combine all the data provided by different surveys (geological, geophysical and geotechnical studies) for converging in a non-ambiguous site characterization model. This requires to evaluate both (i) the reliability of the various site characterization indicators provided by a single or various range of methods, and (ii) then the consistency among the indicators according to the current knowledge and experience feedback of the community.

(i) Regarding the reliability of a single indicator estimated by various methods of acquisition or processing, a Vs velocity profile, V_{S30} or resonance frequency of a site can be derived using different types of data and processing methods, without anyhow any guarantee of consistency between estimates since each method is characterized by its own data quality, resolution and limits. Few benchmarks have been carried out so far, mainly on the shear-wave profiles extraction performance through non-invasive and invasive methods (Asten and Boore, 2005; Cornou et al., 2009; Moss et al., 2008; Cox et al., 2014; Garofalo et al., 2016a; Garofalo et al., 2016b; see Appendix A for further bibliography). These benchmarks have outlined the ability of non-invasive and invasive methods to provide consistent results together with an estimate on inter-analysts variability.

(ii) Consistency among the indicators is most generally addressed in case-study papers focused on deriving a ground velocity model (among many others, Pitilakis et al., 1999; Magistrale et al., 2000; Di Giulio et al., 2008; Koketsu et al., 2009; Pagliaroli et al., 2014; Salloum et al., 2014; Kruiver et al., 2017; see Appendix A for further bibliography). Other studies are focused on correlation between various indicators: e.g. geologic-and terrain-based proxies and V_{S30} (e.g. Wald and Allen, 2007; Yong and al., 2012; Lemoine et al., 2012; Stewart et al., 2014; Wills et al., 2015; Ahdi et al., 2017; see Appendix A for further bibliography), SPT-N blows and Vs profiles (e.g. Hasancebi, N., & Ulusay, R., 2007; Dikmen, 2009; Kuo et al., 2011), V_{S30} and phase velocity at a given wavelength (e.g. Martin and Diehl, 2004; Albarello and Gargani, 2010; see Appendix A for further bibliography).

The lack of standardized procedures to assess quantitatively the quality of site characterization information at a given site prevents an homogenous grading of site characterization information at strong motion sites and at seismic network stations in general. As a consequence, there is no quality information for site characterization in national or international strong motion web sites. When available, the quality grading is related to the method used to extract a given single indicator as in the European Strong Motion database (ESM).

The core information to derive a quality index that account for both the reliability of single indicators and the consistency between various indicators is to be found in the site characterization report at a given strong motion site. A full report should describe in detail instrumental acquisition, data collection, processing parameters and methods, and final interpretation. At European level, some available public reports can be found in ESM (European Strong Motion database; https://esm.mi.ingv.it). At national level, only very few networks also make available site characterization reports (e.g. Switzerland http://stations.seismo.ethz.chl; Italy http://itaca.mi.ingv.it; Turkey http://kyhdata.deprem.gov.tr). These reports can be very detailed when specific measurements at the site are carried out, but most often direct measurements either are not available, or have not been performed, for many stations in Europe, and then the level of information provided by such report can be poor. When specific field surveys are missing, proxies based on geology and/or topography are generally used to define the soil class of a site or of a strong-motion station.

4.2 Overall quality for site characterization

The aim is to propose a strategy to evaluate quantitatively and “objectively” the overall quality of the site characterization analysis for a site. This is the first attempt in Europe and, certainly, the present proposition will be improved after a few years of experience and feedback from users. The present guidelines are to be considered as proposing both a general framework and a specific implementation with some choices which may be discussed and modified in the future.

We define the overall quality metrics according to the 7 indicators defined as mandatory on the basis of the SERA international questionnaire previously described (chapter 2). The overall quality grading is a combination of the following quality indices:

- reliability of each single indicator (quality_index#1);
- weighted sum of the quality of all single indicators (quality_index#2);
- consistency between the values of different indicators (quality_index #3).

The final quality index is an arithmetic average between quality_index#2 and quality_index#3.

The evaluation of the reliability of each single indicator could be performed either by the practitioner(s) in charge of site characterization, or by a network operator or somebody else duly trained in the use of the quality index. Meanwhile, the evaluation of the consistency between various site indicators should be performed by the network operators in charge of providing authoritative metadata.

4.2.1. Quality_Index1 (single indicator)

Quality_index#1 (Q_Index1 hereinafter) varies from 0 to 1 and refers to a single mandatory indicator. It is defined by the following expression

$$Q\_Index1 = [\ (a + b + c)\ \ d\ ]\ /\ (a_{max} + b_{max} + c_{max}) \qquad \text{(eq. 1)}$$

where the definition and the possible values of a, b, c and d are summarized in Table 4.1 and detailed in the following sections.

Table 4.1: Values of factors in eq. 1 for computation of Quality_Index1.

FACTOR	DEFINITION	POSSIBILITY	EXPLANATION	VALUE
A	Method of acquisition and analysis	Documented method through several papers	The method of acquisition and analysis to estimate the target indicator is well documented through several peer-reviewed papers	1
		Undocumented method	The method of acquisition and analysis is not published	0
B	Estimation of indicator	Direct evaluation	The evaluation is based on specific field experiments (see Table 5.3 for direct and inferred examples)	2
		Inferred values	The evaluation is based on inferred values from proxies, empirical relationships or modeling	0
C	Reliability on the value	Yes	The indicator (its value or description) is very reliable	1
		Partial/moderate confidence	In case of partial/moderate confidence	0,5
		No	The indicator, although described in the report, is not reliable	0
D	Completeness of the report	Complete	a well-documented report for the specific indicator is present	1
		Incomplete/partial	report associated to a site is present, but the information is partial and not very detailed	0,5
		No report	The value is provided without any documentation	0

(a) Method of acquisition and analysis [1 or 0] - It defines the reliability of the method of acquisition and analysis to infer the value of the target indicator, on the basis of peer-reviewed papers (Table 4.2).

Table 4.2. Example of peer-reviewed papers connected to each indicator to estimate (a) in eq. 1. Other reference papers can be found in Appendix A.

INDICATOR	EXAMPLE OF PEER-REVIEWED PAPERS OR REPORTS (A=1)
F_0	Nakamura et al., 1989; Field and Jacobs, 1995; SESAME, 2004; Picozzi et al., 2005; Haghshenas et al., 2008; Molnar et al., 2018;
Vs(z) SEISMOLOGICAL BEDROCK DEPTH ENGINEERING BEDROCK DEPTH	Albarello et al. 2011; Asten & Hayashi, 2018; ASTM D4428M-00, 2000; ASTM D7400M-08, 2008; Dikmen, Ü., 2009; Fäh et al., 2010; Foti et al., 2018; Foti et al., 2011; Garofalo et al., 2016; Wathelet et al., 2008; Chakravarthi & Sundararajan, 2007
V_{S30} SITE CLASS	Ahdi et al., 2017; Albarello and Gargani, 2010; Anbazhagan et al., 2013; Boore et al., 2011; Foti et al., 2018; Kuoet al., 2011; Lemoine et al., 2012; Martin & Diehl, 2004; Stewart et al., 2014; Wald & Allen, 2007; Wills et al., 2015; Yong, A., 2016; Yong et al., 2012
SURFACE GEOLOGY	Park and Elrick, 1998; Wills and Clahan, 2006

(b) Estimation of indicator [2 or 0] - It defines the way of evaluating the target indicator: direct or proxy. The evaluation is direct if derived from in-situ field experiments; whereas it is inferred if derived from proxies or empirical relationships (Table 5.3). Because the terms “direct” and “inferred” can be considered ambiguous, we provide for clarity some examples:

- If the target indicator is f_0, both a single-station (noise or earthquake recordings) or extensive noise measurements are considered as a direct evaluation (b = 2).
- If the target indicator is the Vs profile, measurements such as DH, CH, PS-logging, surface-wave inversion are considered a direct evaluation (b = 2).
- If the target indicator is the surface geology, a geological field survey at the site is a direct evaluation (b= 1). If it is already available a detailed cartography (scale finer or equal to 1:10.000), then b=1; when the surface geology is derived from large scale cartography (i.e. 1:100.000), then b= 0.

Other examples of direct and inferred evaluations are reported in Table 4.3.

The way of evaluating the target indicator is considered to be a very important issue in quality assessment, as there is a natural trend for almost all funding agencies to favor the installation of instruments and to neglect the issue of the quality of metadata, which are however critical for data analysis. That is why this item is given a binary value, 2 for actual measurements, and 0 for simply inferred values.

Table 4.3: Examples of criteria for direct or inferred evaluation of the target indicator to estimate (b) in eq. 1

INDICATORS	DIRECT EVALUATION (B=2)	INFERRED EVALUATION (B=0)
F_0	H/V on microtremors or earthquakes Standard Spectral ratio on earthquakes	1D SH response modelling from 1D soil column
V_s	Surface-wave methods CH, DH, P-S logging	Empirical relationship between geotechnical parameters (e.g. SPT, CPT) and V_s[1]
GEOLOGY	Geological field survey at the site detailed geological map (1:10.000) Geological survey or geological log close to the station	Large scale geological map (i.e. 1:100.000)
ENGINEERING BEDROCK DEPTH	Surface-wave methods CH, DH, P-S logging	Empirical relationship between geotechnical parameters (e.g. SPT, CPT) and V_s[1] Inferred from surface geology (geological cross-sections)
SEISMOLOGICAL BEDROCK DEPTH	Surface-wave methods CH, DH, P-S logging Gravimetry study[3]	Empirical relationship between bedrock depth and f_0[2] Inferred from surface geology (geological cross-sections)
V_{s30}	Surface-wave methods CH, DH, P-S logging	Empirical relationship between geotechnical parameters (e.g. SPT, CPT) and/or V_{s30} and/or V_{sz}[1] From geology and/or topography and/or terrain based approach[4]
SOIL CLASS	Surface-wave methods CH, DH, P-S logging	Empirical relationship between geotechnical parameters (e.g. SPT, CPT) and/or V_{s30} and/or V_s[1] From geology and/or topography and/or terrain based approach[4]

[1] Among others, Ohsaki and Iwasaki, 1973; Imai, 1977; Ohta and Goto, 1978; Seed and Idriss, 1981; Chapman et al., 2006; Hasancebi and Ulusay, 2007; Li and Tsai, 2008; Dikmen, 2009; Kuo et al., 2011; Boore 2004; Boore et al., 2011; Xie et al., 2016
[2] Among others, Ibs-Von Seht, 1999; Parolai et al., 2002; Hinzen et al., 2004
[3] Among others, Litinsky, 1989; Stephenson et al., 1993; Abott and Louie, 2000; Zor et al., 2011
[4] Among others, Wald and Allen, 2007; Lemoine et al., 2012; Yong et al., 2012; Stewart et al., 2014; Wills et al., 2015; Xie et al., 2016; Ahdi et al., 2017; Forte et al., 2019

(c) Reliability on the value [1, 0.5 or 0] - It indicates the confidence on the single indicator (or in other terms, the reliability of its value) and it is based on the available information summarized within the intermediate report (see Chapter 3 and Appendix B). Specifically, reliability takes into account criteria on data measurements (including the performance and suitability of the used equipment), reliability of the used methods (including their resolution and commonly admitted rules-of-thumb), repeatability of measurements and appropriate usage of empirical relationship available in literature when indicators are inferred (e.g. V_{S30}-surface topography, Wald and Allen, 2007; VS30- Vs10, Boore et al., 2011; V_{S30}-phase velocity at 40 m wavelength; Martin and Diehl, 2004). Examples of recommendations to estimate confidence on the value of the indicator are listed in Table 4.4. These recommendations are extracted from existing guidelines (e.g. SESAME, 2004; Hunter and Crow, 2012; Foti et al., 2018; see Appendix A for further bibliography).

Table 4.4. Some examples of recommendation to estimate (c) in eq. 1 for each indicator for "data acquisition" experiment involving ambient noise measurements and geological survey.

INDICATORS	HIGH RELIABILITY (C=1)	INTERMEDIATE RELIABILITY (C=0.5)	LOW RELIABILITY (C=0)
F0	sensor cut-off frequency < f_0 time window length > 10/f_0 number of time windows > 10 f_0 fulfills all SESAME criteria	sensor cut-off frequency/5 < f_0 < cut-off frequency 5/f_0 < time window length < 10/f_0 3 < number of time windows < 10 f_0 fulfills some SESAME criteria only Measurements performed during windy days with an unburied or uncovered sensor and f_0 > 1 Hz	cut-off frequency/5 > f_0 time window length < 5/f_0 number of time windows < 3 f_0 does not fulfill any SESAME criteria Measurements performed during windy days with an unburied or uncovered sensor and f_0 < 1 Hz
V_s ***(NON-INVASIVE METHODS)***	sensor cut-off frequency < minimum frequency of dispersion curve maximum wavelength of fundamental mode of Rayleigh wave / 2 > maximum reported depth surface layer thickness > minimum wavelength/3 (only for fundamental Rayleigh wave mode inversion) minimum reported V_s is in the order range of the minimum phase velocity	sensor cut-off frequency/2 < minimum frequency of dispersion curve < sensor cut-off frequency maximum wavelength of fundamental mode of Rayleigh wave / 2 < maximum reported depth < maximum wavelength of fundamental mode of Rayleigh wave surface layer thickness < minimum wavelength/3 (only for Rayleigh wave mode 0 inversion)	sensor cut-off frequency/2 > minimum frequency of dispersion curve maximum wavelength of fundamental mode of Rayleigh wave < maximum reported depth surface layer thickness < minimum wavelength/5 (only for Rayleigh wave mode 0 inversion)

	maximum reported V_s is in the order range of the maximum phase velocity $V_P > V_s$		maximum reported $V_s >$ 3 maximum phase velocity $V_s > V_P$
GEOLOGY	geological survey or log at the location of strong motion		geological log far from the location of strong motion (> 500 m)
ENGINEERING BEDROCK DEPTH	same as Vs(z)		
SEISMOLOGICAL BEDROCK DEPTH	same as Vs(z) f_0=Vs/4H does apply (within 10%), with H the seismological bedrock depth	same as Vs(z) Vs/4H does not provide f_0 within 20%, , with H the seismological bedrock depth	same as Vs(z) Vs/4H does not provide f_0 within 20%, , with H the seismological bedrock depth
V_{S30}	same as Vs(z) V_{S30} in the range of expected values of available local studies (i.e. Microzonation studies or specific experiment in the same area)	same as Vs(z) V_{S30} in the range of expected values as from comparative tables (i.e. Table 3 in Foti et al., 2018, or EC8 prescription for ground type)	same as Vs(z) V_{S30} out of the range of high and intermediate reliability
SOIL CLASS	same as VS30 and bedrock	same as VS30 and bedrock	same as VS30 and bedrock

(d) Completeness of the report [1, 0.5 or 0] - it defines whether there exists a report describing step by step the field survey and the data processing to evaluate the target indicator. Please note that the presence of a detailed report is very important in eq. 1; in case of the absence of any report documenting the value of a given indicator, the corresponding quality_index1 is assigned a zero value. For sake of clarity, see the example of complete reports provided in Chapter 3.

4.2.2 Quality_Index2 (overall characterization)

Whereas Q_index#1 is computed through eq. 1 for each single mandatory indicator, Quality_Index2 is a weighted sum computed on the Q_Index#1 of all indicators evaluated at the target site and varies from 0 to 1.

The expression of Quality_Index2 is

Q_Index2=(w1 Q_Index1mandatory1 + w2 Q_Index1mandatory2 + ...+ w_n Q_Index1mandatoryn) / (w1 + w2 …..+ wn) (eq. 2)

where wi are the weights relative to a single mandatory indicator and n indicates the total number of mandatory indicators (n is equal to 7 as resulting from the questionnaire assuming a threshold value > 50%; see table 2.2). Note that even if not all the 7 indicators have been measured or inferred for a given site, the quality_index_2 will remain a weighted average of all the seven Q_Index1 values, the latter values being equal to 0 for all missing indicators.

Various options have been considered to assign the values of weights wi. One option was to derive them in direct link with the importance resulting from the survey (for instance wi = 2 (pi - 0.5) where pi is the "mandatory" percentage as displayed in Figure 2.1). However, following the suggestions from the international SERA workshop, we have questioned the robustness of such numbers (it could slightly vary for another set of answering individuals or teams); we then preferred to have three simple classes of weight as listed in Table 5.4:

- A full weight of 1 for the two indicators considered as the most important from the survey, i.e., f_0 and the velocity profile VS(z);
- A half-weight of 0.5 for almost all other indicators, which correspond either to values derived from other primary measurements (e.g., V_{S30} and bedrock depth from velocity profile Vs(z) and f_0), or to more qualitative information ("geology");
- A quarter weight (0.25) for indicator "site class", as it is relatively qualitative and derives from other already weighted measurement (V_{S30}, engineering bedrock depth).

Because the weights are assumed to be constant values (Table 4.5) and once the Q_Index1 is defined for all the mandatory indicators (Table 5.1), the computation of Q_Index2 by eq. 2 is then straightforward and can be performed by non-specialist or networks operators.

Table 4.5. Weights of the mandatory indicators for computation of Quality_Index 2 (see eq. 2).

INDICATOR	*IMPORTANCE FROM THE QUESTIONNAIRE*	*WEIGHT W_i*
F0	0,88	1
V_{S30}	0,64	0,5
SURFACE GEOLOGY	0,61	0,5
V_s(z)	0,72	1
DEPTH OF SEISMOLOGICAL BEDROCK	0,57	0,5
DEPTH OF ENGINEERING BEDROCK	0,55	0,5
SOIL CLASS	0,57	0,25

A plot of Q_Index2, as a function of various sets of available indicators, is shown in Figure 4.1. This trend was computed varying the b value of Q_Index1 (see eq. 1); i.e. b=2 for direct evaluation or b=0 for inferred values. The Q_Index2 was computed by eq. 2 with all the other parameters (a, c and d in eq. 1) being kept equal to 1 and with the weights of Table 4.5. The resulting values of Q_Index2 were sorted in the plot of Fig. 4.1. from the maximum value.

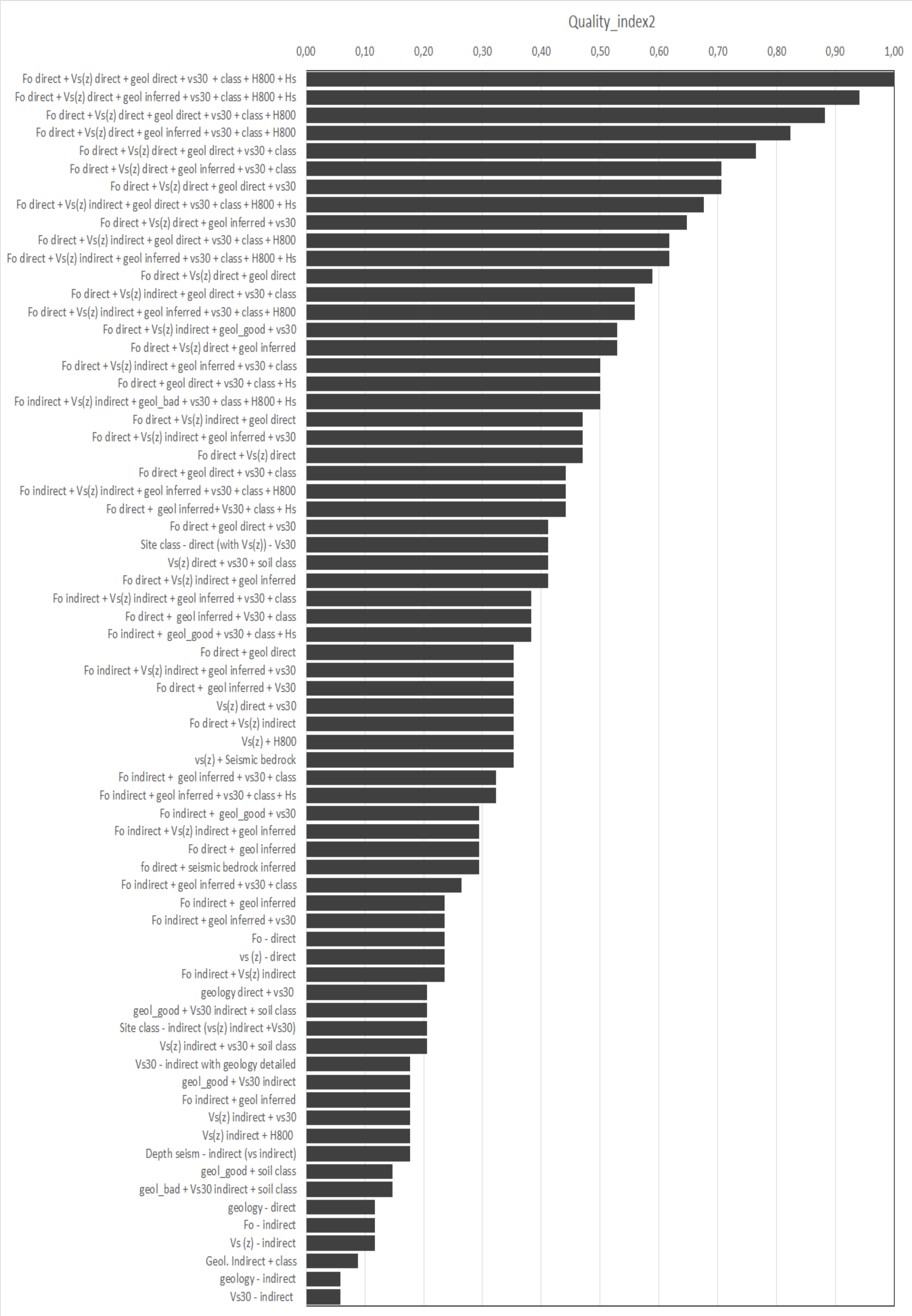

Figure 4.1: Example of Quality_Index2 for various set of mandatory indicators.

4.2.3. Quality_Index3 (consistency)

Quality_Index#3 (Q_Index3 hereinafter) refers to the overall consistency between the various indicators and varies from 0 to 1.

Specifically, Q_Index3 evaluates consistency of various couples of indicators according to the current state of knowledge of the community. If estimates for a given couple of indicators (e.g f_0 and V_{S30}, geology and V_{S30}, etc.) are not within the range of reported values, then these two estimates are considered as not consistent with one another. For example, if f_0 is 1 Hz and seismic bedrock depth is 10 m, most probably seismic bedrock depth or f_0 are underestimated, unless detailed site characterization reports indicate very peculiar site (for the given example, extremely soft materials such as Mexico City lacustrine deposits). Since estimation of the various indicators (f_0, Vs(z), V_{S30}, surface geology, site class, seismological and engineering bedrocks) may be done by different research groups or practitioners, we recommend this evaluation to be performed by the network operator or an external expert.

The consistency among various couple of indicators should be performed between the following mandatory indicators: f_0, Vs(z), V_{S30}, H_{800} (engineering bedrock), seismic bedrock depth and surface geology. This can be assessed through empirical relationships provided by scientific literature (some reference papers are listed in Table 4.6). However, because empirical relationships can refer to a specific area or database, the consistency should take into account all the local available studies (if any, for example in the context of microzoning or past research activity) near the target site to check the reliability between indicators and the similarities between multiple and independent measurements (e.g. measurements performed in the same area at different times, by different groups or using distinct methods).

The computation of Q_Index3 is given by the sum of consistency values (2nd column of Table 4.6) among the five couples of indicators of Table 4.6 (n=5 in eq. 3), for which published references are available. The consistency at a specific site is computed only for the available indicators (e.g. if only $V_{S30}$and geological information are reported for a site, then the consistency (cons) should be checked only for the couple V_{S30}-surface geology).

Q_Index3= [cons(f_0, V_{S30}) + cons(f_0, seismic_bedrock_depth) + cons(f_0, engineering_bedrock_depth) + cons(H_{800}, V_{S30}) + cons(V_{S30}, geology)] / n (eq. 3)

Some examples of scatter plots between couples of indicators are given in the next section 4.3.

Table 4.6. Consistency between couple of parameters; the consistency of each couple can be evaluated by empirical relations (see scatter plots in section 4.3).

Couple of Indicators	**Possible value of consistency**	**References**
F_0 - V_{s30}	0 No consistency 1 consistency	Ghofrani and Atkinson,2014; Luzi et al. 2011
F_0 - Depth of seismic bedrock	0 No consistency 1 consistency	Derras et al., 2017; Luzi et al., 2011; Gosar and Lenart, 2010
F_0 - Depth of engineering bedrock	0 No consistency 1 consistency	Derras et al., 2017
V_{s30} - H_{800}	0 No consistency 1 consistency	Derras et al., 2017
V_{s30} - Surface geology	0 No consistency 1 consistency	Wills et al., 2000; Foti et al., 2018; Stewart et al. 2014, Ahdi et al., 2017 ; Forte et al., 2019

4.3 Consistency of indicators couples

There are numerous papers showing empirical relationships between the mandatory indicators: f_o-seismic bedrock (e.g. Ibs-Von Seht, 1999; Parolai et al., 2002; Hinzen et al., 2004; Gosar and Lenart, 2009), f_0-V_{S30} (e.g. Luzi et al., 2011; Gofhrani and Atkinson, 2014); f_0-H_{800} (e.g. Derras et al., 2017), V_{S30}-surface geology (e.g. Wills et al., 2000; Stewart et al., 2014). However, because these empirical relationships usually refer to a specific area or database, we used 935 real V_s profiles composed of 602 Japanese sites from Kiknet network (http://www.kyoshin.bosai.go.jp/), 243 Californian sites from Boore (2003) (http://quake.usgs.gov/~boore), 21 European strong-motion sites (Di Giulio et al., 2012), 33 french sites (Hollender et al., 2018) and 36 italian sites from ITACA database (Luzi et al. 2019). List of stations are provided in Table 4.7. For those profiles having shear-wave velocity lower than 800 m/s in the deepest layer, we modified the V_s value in the deepest layer such as to reach 800 m/s. From this set of Vs profiles, we then computed V_{S30}, site class, H_{800}, f_0 from the computed SH amplification using the reflectivity method (Kennet, 1983), and seismic bedrock depth by extracting the depth for which the resonance frequency provided by the Rayleigh's method (Dobry et al., 1976) is similar to the measured f_0 .

Table 4.7. Station codes used for the scatter plots between various indicators (Table 4.6).

NETWORK	STATION CODE
ITACA (LUZI ET AL. 2019)	ALF ALT ARI ASG BRM BRZ CNG CRN CSC CSD CST DMN FRN GLD GSN LNG LRS MLC MLD MNS MTL MZR NAS NCS NZZ PGL PNN RCC RNC SGR SNG SRP STS TDG TLM2.B VLS2.B
HOLLENDER ET AL., (2018)	CALF GRN IRPV IRVG NALS NBOR OCKE OCOL OCOR OGAN OGAP OGBL OGCA OGCH OGDH OGFH OGIM OGLE OGMA OGME OGMU OGPC PYAS PYAT PYBB PYLI PYLO PYLU PYOR STBO STDM STSM SURF
DI GIULIO ET AL., (2012)	ATHENC ATHENS BENEVE CERETD CERRET COLFIO DUEZCn KORI_C KORI_D SAKARY cereto colfmo duezce edessa eurose forli. knidi. nestos nocera norcia sturno
BOORE (2003)	10128P 10128S ANDP.V ANSP.V ANSS.V AP1P.V AP1S.V AP2P.V AP2S.V APTP.V APTS.V BCSP.V BCSS.V BOCP.V BOCS.V BPBP.V BRAS.V BVAP.V Bpbs.v CALP.V CALS.V CCGP.V CCGS.V COEP.V COES.V COWP.V COWS.V COYP.V COYS.V COZS.V CPBP.V CPBS.V CRDP.V CRDS.V CRLP.V CRLS.V CRWP.V CRWS.V CSCP.V CSCS.V CTMS.V CVRP.V CVRS.V CXFSP. CXFSS. DIGP.V DIGS.V DPBP.V DPBS.V DZNP.V DZNS.V EC10P. EC10S. EC11P. EC11S. EC13P. EC13S. EC2P.V EC2S.V EC3P.V EC3S.V EC4S.V EC5S.V EC6P.V EC6S.V EC7P.V EC7S.V EC8P.V EC8S.V EC9P.V EC9S.V ECDAP. ECDAS. ELCP.V ELCS.V ELGS.V EMBP.V EMBS.V ESC2P. ESC2S. ESCS.V FFSS.V FMTP.V FMTS.V FRSP.V FRSS.V FTJP.V FTJS.V GIL2EP GIL2ES GIL2UP GIL2US GL7P.V GL7S.V GRVP.V GRVS.V GSTS.V GVDP.V GVDS.V HLR3P. HLR3S. HPOP.V HPOS.V HRSP.V HRSS.V HSTP.V HSTS.V I10P.V I10S.V ICSP.V ICSS.V JCKP.V JCKS.V JGBP.V JGBS.V JMBP.V JMBS.V KESS.V KNWS.V LADP.V LADS.V LAOP.V LAOS.V LFSP.V LFSS.V LFYP.V LFYS.V LISP.V LISS.V LLNP.V LLNS.V LVIP.V LVIS.V MCGS.V MCPP.V MCPS.V MDRP.V MDRS.V MGSP.V MGSS.V MTMP.V MTMS.V MWDS.V NPBS.V OBGP.V OBGS.V OHWP.V OHWS.V OVH2P. OVH2S. PA2P.V PA2S.V PFSP.V PFSS.V PGCS.V PHIP.V PHIS.V PNFS.V POTP.V POTS.V PPPS.V PUTP.V PUTS.V RD7S.V RDLP.V REDP.V REDS.V RINP.V RINS.V RIOP.V RIOS.V RSEP.V RSES.V RVMP.V RVMS.V SB1P.V SB1S.V SCAP.V SCAS.V SCWS.V SFOP.V SFOS.V SFSP.V SFSS.V SIMP.V SIMS.V SLACP. SLACS. SMSP.V SMSS.V SMWS.V SOPP.V SOPS.V SOWP.V SOWS.V SPKP.V SPKS.V STMP.V STMS.V SUBP.V SUBS.V SVAP.V SVAS.V TACP.V TACS.V TARP1. TARS1. TRAP2. TRAS2. TRIP.V TRIS.V TWPS.V VAHS.V VARP.V VARS.V VCGP.V VCGS.V VTGP.V VTGS.V VYCP.V VYCS.V WDSP.V WDSS.V WEBP.V WEBS.V WFSP.V WFSS.V WHRP.V WHRS.V WILS.V WMRP.V WMRS.V WOCP.V WOCS.V WTPP.V WTPS.V WVANP. WVANS. WVASP. WVASS. WWDP.V WWDS.V mwdp.v
KIKNET	ABSH02 ABSH03 ABSH04 ABSH05 ABSH06 ABSH07 ABSH08 ABSH09 ABSH10 ABSH11 ABSH12 ABSH13 ABSH14 ABSH15 AICH04 AICH05 AICH06 AICH07 AICH08 AICH09 AICH10 AICH11 AICH12 AICH14 AICH15 AICH16 AICH17 AICH18 AICH19 AICH20 AICH21 AICH22 AKTH01 AKTH02 AKTH03 AKTH04 AKTH05 AKTH06 AKTH07 AKTH08 AKTH09 AKTH10 AKTH11 AKTH12 AKTH13 AKTH14 AKTH15 AKTH16 AKTH17 AKTH18 AKTH19 AOMH01 AOMH02 AOMH03 AOMH05 AOMH06 AOMH07 AOMH08 AOMH09 AOMH10 AOMH11 AOMH12 AOMH13 AOMH14 AOMH15 AOMH16 AOMH17 AOMH18 CHBH14 CHBH16 EHMH01 EHMH02 EHMH03 EHMH04 EHMH05 EHMH06 EHMH07 EHMH08 EHMH09 EHMH10 EHMH11 FKIH01 FKIH02 FKIH03 FKIH04 FKIH05 FKIH06 FKIH07 FKOH01 FKOH02 FKOH03 FKOH04 FKOH05 FKOH06 FKOH07 FKOH08 FKOH09 FKSH01 FKSH02 FKSH03 FKSH04 FKSH05 FKSH06 FKSH07 FKSH08 FKSH11 FKSH12 FKSH13 FKSH14 FKSH15 FKSH16 FKSH17 FKSH18 FKSH19 GIFH03 GIFH04 GIFH05 GIFH06 GIFH07 GIFH08 GIFH09 GIFH10 GIFH11 GIFH12 GIFH13 GIFH14 GIFH15 GIFH16 GIFH17 GIFH18 GIFH19 GIFH20 GIFH21 GIFH22 GIFH23 GIFH24 GIFH25 GIFH26 GIFH27 GIFH28 GIFH29 GNMH07 GNMH08 GNMH09 GNMH10 GNMH11 HDKH01 HDKH02 HDKH03 HDKH04 HDKH05 HDKH06 HDKH07 HRSH01 HRSH02 HRSH03 HRSH04 HRSH05 HRSH06 HRSH07 HRSH08 HRSH09 HRSH10 HRSH11 HRSH12 HRSH13 HRSH14 HRSH15 HRSH16 HRSH17 HRSH18 HYGH01 HYGH02 HYGH03 HYGH04 HYGH05 HYGH06 HYGH07 HYGH08 HYGH09 HYGH10 HYGH11 HYGH12 HYGH13 HYGH14 HYGH15 HYMH01 HYMH02 HYMH03 IBRH11 IBRH12 IBRH13 IBRH14 IBRH15 IBRH16 IBRH17 IBRH18 IBUH01 IBUH02 IBUH03 IBUH04 IBUH05 IBUH06 IBUH07 IKRH01 IKRH02 IKRH03 ISKH01 ISKH03 ISKH06 ISKH08 ISKH09 IWTH01 IWTH02 IWTH03 IWTH04 IWTH05 IWTH06 IWTH07 IWTH08 IWTH09 IWTH10 IWTH11 IWTH12 IWTH13 IWTH14 IWTH15 IWTH16 IWTH17 IWTH18 IWTH19 IWTH20 IWTH21 IWTH22 IWTH23 IWTH24 IWTH25 IWTH26 IWTH27 KGSH01 KGSH02 KGSH03 KGSH04 KGSH05 KGSH06 KGSH07 KGSH09 KGSH10 KGSH11 KGSH12 KGSH13 KGWH01 KGWH02 KGWH03 KGWH04 KKWH01 KKWH02 KKWH03 KKWH04 KKWH05 KKWH06 KKWH07 KKWH08 KKWH09 KKWH10 KKWH11 KKWH12 KKWH13 KKWH14 KKWH15 KMMH01 KMMH02 KMMH03 KMMH04 KMMH05 KMMH06 KMMH07 KMMH08 KMMH09 KMMH10 KMMH11 KMMH12 KMMH13 KMMH14 KMMH15 KMMH16 KMMH17 KNGH18 KNGH19 KNGH20 KNGH21 KOCH01 KOCH02 KOCH03 KOCH04 KOCH07 KOCH08 KOCH10 KOCH11 KSRH01 KSRH02 KSRH03 KSRH04 KSRH05 KSRH06 KSRH07 KSRH08 KSRH09 KSRH10 KYTH01 KYTH02 KYTH04 KYTH05 KYTH06 MIEH01 MIEH02 MIEH03 MIEH04 MIEH05 MIEH06 MIEH07 MIEH08 MIEH09 MIEH10 MYGH01 MYGH02 MYGH03 MYGH04 MYGH05 MYGH06 MYGH07 MYGH08 MYGH09 MYGH10 MYGH11 MYGH12 MYZH01 MYZH02 MYZH03 MYZH04 MYZH06 MYZH07 MYZH08 MYZH09 MYZH10 MYZH11 MYZH12 MYZH13 MYZH14 MYZH15 MYZH16 NARH01 NARH02 NARH03 NARH04 NARH05 NARH06 NARH07 NGNH08 NGNH09 NGNH10 NGNH11 NGNH13 NGNH14 NGNH15 NGNH16 NGNH17 NGNH18 NGNH19 NGNH20 NGNH21 NGNH22 NGNH23 NGNH24 NGNH25 NGNH26 NGNH27 NGNH28 NGNH29 NGNH30 NGNH31 NGNH32 NGNH33 NGNH35 NGSH01 NGSH02 NGSH03 NGSH04 NGSH05 NIGH02 NIGH03 NIGH04 NIGH05 NIGH06 NIGH07 NIGH08 NIGH09 NIGH10 NIGH11 NIGH12 NIGH13 NIGH14 NIGH15 NIGH16 NIGH17 NIGH18 NIGH19 NMRH01 NMRH02 NMRH03 NMRH04 NMRH05 OITH01 OITH02 OITH03 OITH05 OITH06 OITH07 OITH08 OITH09 OITH11 OKYH01 OKYH03 OKYH04 OKYH05 OKYH06 OKYH07 OKYH08 OKYH09 OKYH10 OKYH11 OKYH12 OKYH13 OKYH14 OSKH01 OSKH02 OSKH03 OSKH04 OSMH01 OSMH02 RMIH01 RMIH02 RMIH03 RMIH04 RMIH05 SAGH01 SAGH02 SAGH03 SAGH04 SAGH05 SBSH08 SBSH09 SIGH01 SIGH02 SIGH03 SIGH04 SITH05 SITH06 SITH07 SITH08 SITH09 SITH10 SITH11 SMNH01 SMNH02 SMNH03 SMNH04 SMNH05 SMNH06 SMNH07 SMNH08 SMNH09 SMNH10 SMNH11 SMNH12 SMNH13 SMNH14 SMNH15 SMNH16 SOYH01 SOYH02 SOYH03 SOYH04 SOYH05 SOYH06 SOYH07 SOYH08 SOYH09 SOYH10 SRCH01 SRCH02 SRCH03 SRCH04 SRCH05 SRCH06 SRCH07 SRCH08 SRCH09 SRCH10 SZOH24 SZOH25 SZOH28 SZOH29 SZOH30 SZOH31 SZOH32 SZOH33 SZOH34 SZOH35 SZOH36 SZOH37 SZOH38 SZOH39 SZOH40 SZOH41 SZOH42 SZOH43 TCGH07 TCGH08 TCGH09 TCGH10 TCGH11 TCGH12 TCGH13 TCGH14 TCGH15 TCGH16 TKCH01 TKCH02 TKCH03 TKCH04 TKCH05 TKCH06 TKCH07 TKCH08 TKCH10 TKCH11 TKSH01 TKSH03 TKSH04 TKSH05 TKYH12 TKYH13 TTRH01 TTRH02 TTRH03 TTRH04 TTRH05 TTRH06 TTRH07 TYMH01 TYMH02 TYMH05 TYMH06 TYMH07 WKYH01 WKYH02 WKYH03 WKYH04 WKYH05 WKYH06 WKYH07 WKYH08 WKYH09 WKYH10 YMGH01 YMGH02 YMGH03 YMGH04 YMGH05 YMGH06 YMGH07 YMGH08 YMGH09 YMGH10 YMGH11 YMGH12 YMGH13 YMGH14 YMGH15 YMGH16 YMGH17 YMNH09 YMNH10 YMNH11 YMNH12 YMNH13 YMNH14 YMTH01 YMTH03 YMTH04 YMTH05 YMTH06 YMTH07 YMTH08 YMTH09 YMTH10 YMTH11 YMTH12 YMTH13 YMTH14 YMTH15

Scatter plots for the different set of indicators (Table 4.6) computed on the 935 sites are indicated in Figure 4.2 (f_0 - V_{s30}), Figure 4.3 (f_0 - depth of seismic bedrock), Figure 4.4 (f_0 - depth of engineering bedrock) and Figure 4.5 (depth of engineering bedrock - V_{S30}). The color scale in the figures is scaled to soil class category following EC8 prescriptions: 1 (dark blue) class A, 2 (light blue) class B, 3 (green) class C, 4 (orange) class D and 5 (yellow) class E.

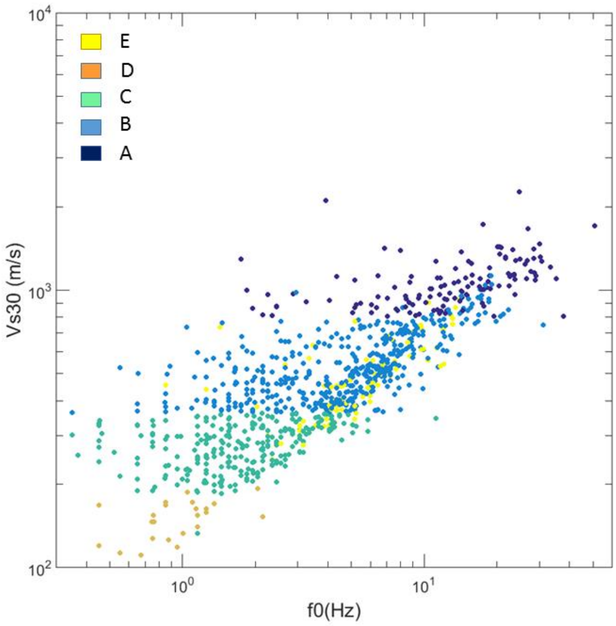

Fig. 4.2. Scatter plot for the couple of indicators (f_0 - V_{s30}).

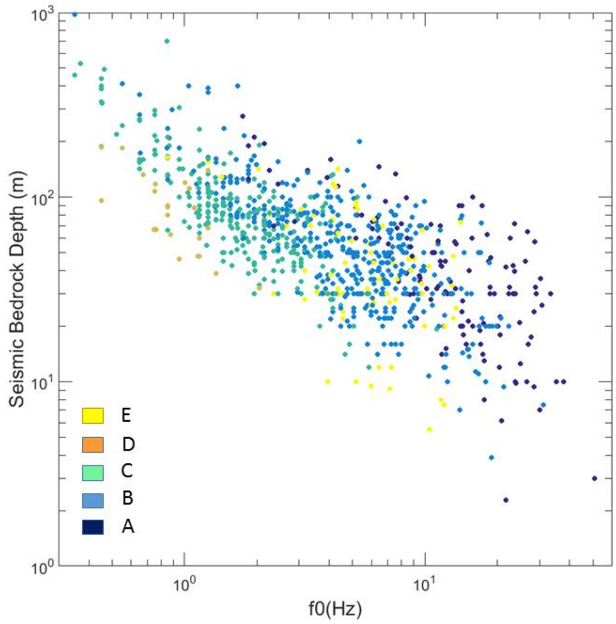

Figure 4.3: Scatter plot for the couple (f_0-depth of seismic bedrock).

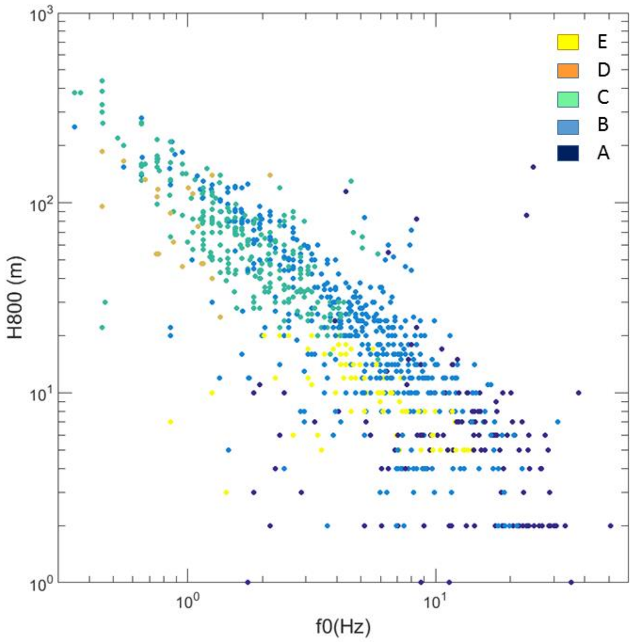

Fig. 4.4. Scatter plot for the couple (f0-depth of engineering bedrock).

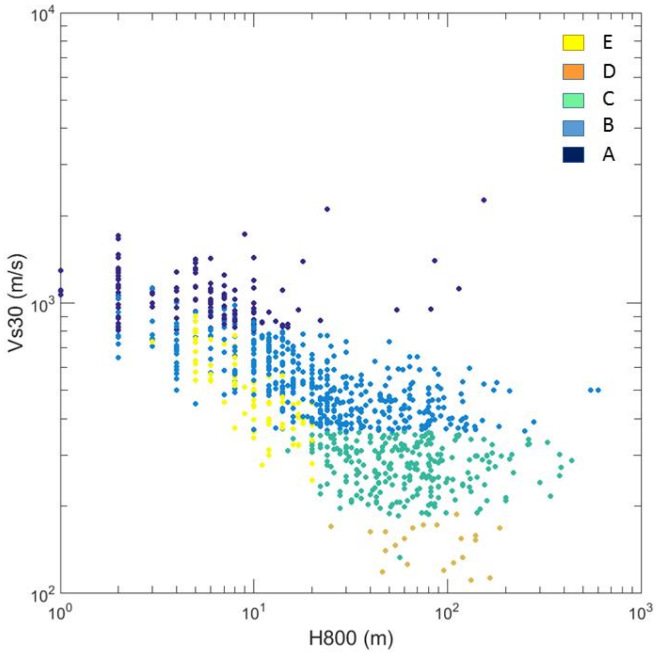

Figure 4.5: Scatter plot for the couple (depth of engineering bedrock - V_{S30}).

Note that the couple (depth of seismic bedrock - V_{s30}) was reported in Fig. 4.6 for completeness. However, we prefer to not consider it in the consistency check of Table 4.6 because the scatter plot does not show a clear trend between these two indicators: this behavior is likely because the V_{s30} value is related to the depth of seismic bedrock only when the stiff interface is very shallow (i.e. at a depth < 30 m).

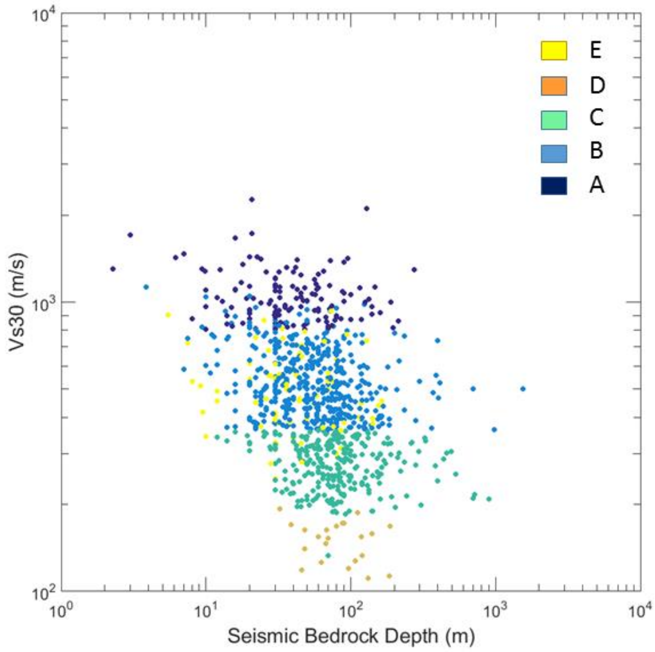

Fig. 4.6. Scatter plot for the couple (depth of seismic bedrock - V30). Please note that this couple was not used in the consistency check (Table 4.6)

About the correlations between V_{S30} and surface geology, this is even more difficult to represent in a single scatter plot because the geology, which is very region dependent, can be described in several ways; for example using geological maps at various space scale or using lithological or geological description that are correlated in first approximation to V_{S30} values. In any case, we recommend to verify at the target site the consistency between V_{S30} and local geology using expected values of velocity ranges for typical soils and rocks (Fig. 4.7 and Table 4.8) as provided by a priori information and past studies (for example in the context of microzonation activities or from existing geotechnical-engineering database).

Table 4.8. Expected value of shear-wave velocities for soils and rocks; extracted from Table 3 of Foti et al. 2018.

Geomaterial	V_S (m/s)
Soft clay	80–200
Stiff clay	200–600
Loose sand	80–250
Dense sand	200–500
Gravel	300–900
Weathered rock	600–1000
Competent rock	1200–2500

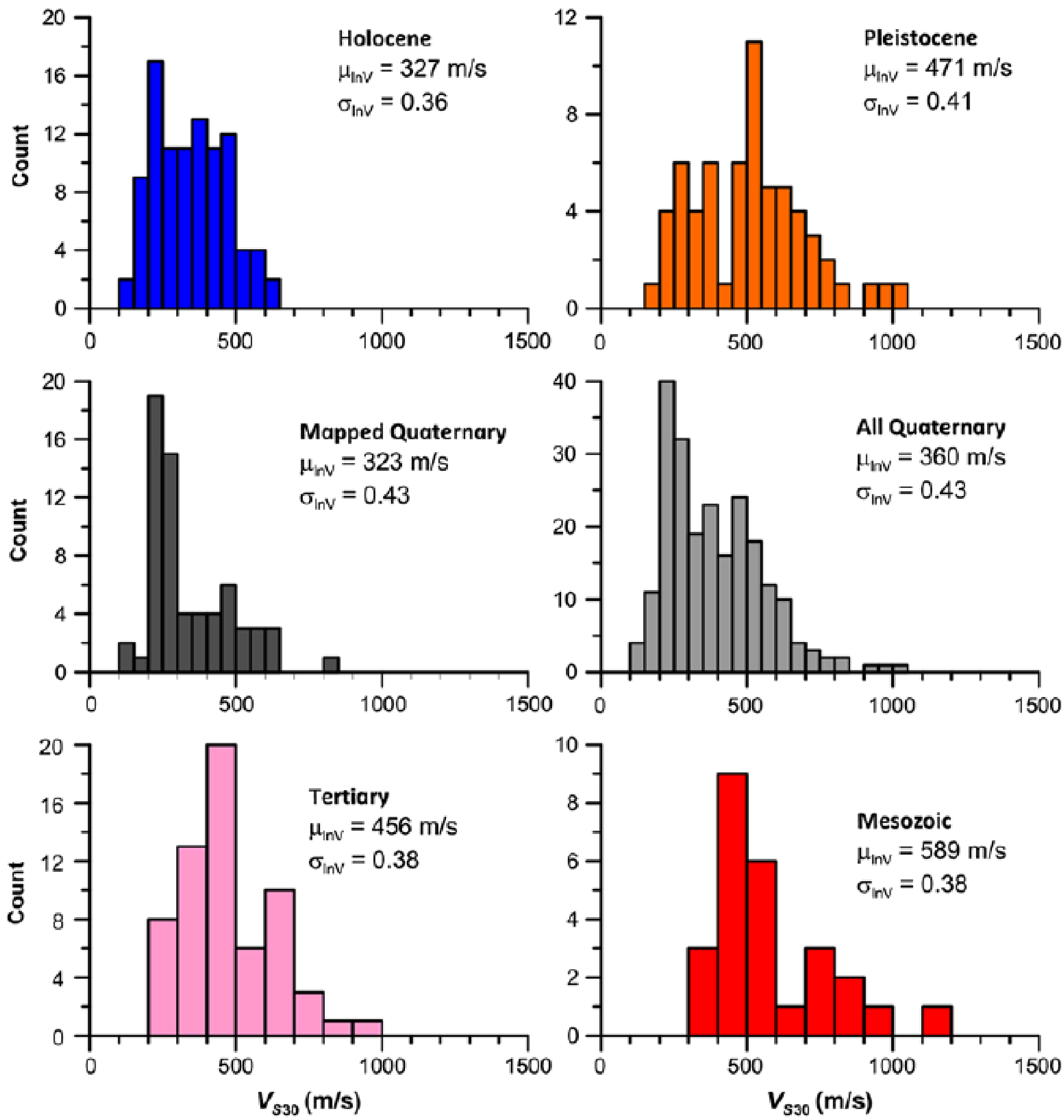

Fig. 4.7. Histogram showing V_{S30} distribution for Greek sites sorted by geological age. The profile database consisted of 341 sites in Greece. Redrawn from Stewart et al. 2014.

4.4 Final Quality Index

The final quality index is computed as the arithmetic mean between Q_Index2 (eq. 2) and Q_Index3.

Final_Quality_Index = (Q_Index2 + Q_Index3)/2 (eq. 3)

The range of values of Final_Quality_Index is spanning from 0 to 1. A value of 1 is for a site with a very thorough and reliable seismic characterization, 0 is assigned to a site badly or not characterized.

4.5 Example of Quality Metrics Computation

This example is referring to three generic sites:

- Site A: all indicators are well estimated except the confidence on depth of seismic bedrock that is intermediate;
- Site B: as Site A, except that confidence on Vs(z) is low. As a consequence, reliability of V_{S30}, soil class and depth of engineering and seismic bedrock is low;
- Site C: there available only very good information on f_0;

Q_Index1. For each indicator, the values of a, b, c and d are assigned following chapter 4.2.1.

f_0		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	1
direct or not	b=[0;2]	2	2	2
reliability	c=[0;0.5;1]	1	1	1
report	d=[0;0.5;1]	1	1	1
		1,00	**1,00**	**1,00**

depth of engin. bedrock		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	d=[0;0.5;1]	1	0	0
report	c=[0;0.5;1]	1	1	0
		1,00	**0,75**	**0,00**

Vs(Z)		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	c=[0;0.5; 1]	1	0	0
report	d=[0;0.5;1]	1	1	0
		1,00	**0,75**	**0,00**

depth of seismic bedrock		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	d=[0;0.5;1]	0,5	0	0
report	c=[0;0.5;1]	1	1	0
		0,88	**0,75**	**0,00**

V_{S30}		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	c=[0;0.5;1]	1	0	0
report	d=[0;0.5;1]	1	1	0
		1,00	**0,75**	**0,00**

soil class		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	d=[0;0.5;1]	1	0	0
report	c=[0;0.5;1]	1	1	0
		1,00	**0,75**	**0,00**

surface geology		SITE-A	SITE-B	SITE-C
method	a=[0;1]	1	1	0
direct or not	b=[0;2]	2	2	0
reliability	c=[0;0.5;1]	1	1	0
report	d=[0;0.5;1]	1	1	0
		1,00	**1,00**	**0,00**

Q_Index2. It is computed by using the eq. 2, based on the Q_Index1 values assigned previously, and with the weights following Table 4.5

		Q1_SITE-A	Q1_SITE-B	Q1_SITE-C
weight f_0=	1	1	1	1
weight Vs(z)=	1	1	0,75	0
weight V_{S30}=	0,5	1	0,75	0
weight surface geology=	0,5	1	1	0
weight depth of seismic bedrock=	0,5	0,88	0,75	0
weight depth of eng bedrock=	0,5	1	0,75	0
weigh soil class=	0,25	1	0,75	0
sum-weight=	4,25			
Q_Index2=		**0,99**	**0,84**	**0,24**

Q_Index3. The consistency between the four couples of indicators is assigned based on eq. 3 and Table 4.6.

	SITE-A	SITE-B	SITE-C
f_0-V_{S30}	1	1	0
f_0-H seismic bedrock	1	1	0
Vs(z)-V_{S30}	1	1	0
V_{S30}-surface geology	1	1	0
Q_Index3=	**1**	**1**	**0**

Final_Q_Index. The Final Quality Index is given by eq. 4.

Final Quality Index	SITE-A	SITE-B	SITE-C
	0,99	**0,92**	**0,12**

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6 Appendix A: bibliography and methodologies

Appendix A summarizes the bibliography related to indicators and methodologies used in seismic characterization analysis. Although it is not exhaustive, it should be intended as an indicative summary of references and guidelines for the best practice of measurement and analysis, as collected within the SERA NA5 activities and integrating the Bibliography of the main text.

The list of Indicators we refer to in this Appendix, is shown in Table 1, followed by the Bibliography grouped according to their affinity.

Table 1 - List of site-effect indicators, as derived from the first Questionnaire. Number indicates the group where to find the Bibliography.

Scalar parameters	**Group**
f_0 (resonance frequency)	1
$f_1, f_2, ... f_n$(higher frequency peaks)	1
Vsz (average Vs at different depth=5, 10, 20 m)	2
V_{S30} (seismological or geological)	2
Vs_seismic_bedrock and H_seismic_bedrock (Vs and depth of the seismic bedrock)	2
H800 or H1000 (depth at Vs= 800 m/s or 1000 m/s)	
Kappa0	3
A_0, A_1 … amplitude from HV, SSR and HVnoise	1
Site Classification	4
Depth-dependent parameters	
Vs(z), Vp(z) profile from non-invasive measurements	2
Non linear curves (normalized stiffness modulus G/G0-shear strain and damping D-shear strain curves)	5
Geotechnical Parameters	5
CRR (cyclic resistance ratio)	5
Water table depth	
Frequency-dependent parameters	
Directional amplification	1
Curve of spectral ratio (from earthquake or noise)	1
Ground motion polarization	1
Dispersion curve	2
Rayleigh wave ellipticity curve	2
Fa, Housner Intensity (amplification factors)	
Kappa and Q	3
non linearity potential (resonance frequency shift and amplitude variation as a function of earthquake magnitude)	
Geological/Morphological attributes	
Surface geology	6
Geo-stratigraphic 1D profile (multidisciplinary characterization)	6
(3D) Geological conceptual model	6

Slope, ridge, topographic-geometrical factors	6
terrain categories (geomorphometry)	6
Geometrical parameter with respect to a basin and Near-surface heterogeneities (any parameter related with 2D or 3D structure (surface topography or underground)	6
Advanced site effects indicators	
transfer function from 1D/2D/3D numerical modeling	7
1D/2D/3D resonance behavior and normal modes	
Site transfer amplification function, f_0	1
Aggravation factors for basin or topography (e.g. the ratio between 2D, or recorded motion, and 1D acceleration response spectra at the basin surface)	7
2D/3D site effects (including basin effects)	
Vs profile and Vs(x,y,z)	
Empirical TF from downhole arrays	
duration lengthening (frequency-dependent lengthening of seismic ground-motion duration)	

6.1 Indicators of Group 1

TYPE OF INDICATOR

f_0 (resonance frequency)

$f_1, f_2, \ldots f_n$ (higher frequency peaks)

A_0, A_1 … amplitude from HV (noise and earthquake), SSR (earthquake)

Site transfer amplification function

Preferential direction of Ground motion

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6.2 Indicators of Group 2

TYPE OF INDICATOR

Vsz (average Vs at different depth=5, 10, 20 m)
V_{S30} (seismological, geological)
Vs and depth of the seismic or engineering bedrock
Vs, Vp profile from non-invasive and invasive measurements
Dispersion curve
Rayleigh wave ellipticity curve

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6.3 Indicators of Group 3

TYPE OF INDICATOR
Kappa0
Kappa and Q

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6.4 Indicators of Group 4

TYPE OF INDICATOR
soil (site) class and building codes

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6.5 Indicators of Group 5

TYPE OF INDICATOR

Non linear curves (normalized stiffness modulus G/G0-shear strain and damping D-shear strain curves)
Geotechnical Parameters
CRR (cyclic resistance ratio)

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6.6 Indicators of Group 6

TYPE OF INDICATOR

Slope, ridge, topographic-geometrical factors
Surface geology
Geo-stratigraphic 1D profile
Geological conceptual model
Geometrical parameter (surface topography or underground lithological heterogeneity)

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6.7 Indicators of Group 7

TYPE OF INDICATOR
2D/3D site effects (including basin effects)
Aggravation factors for basin or topography

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7 Appendix B: Templates for intermediate report

The template proposed in these Guidelines is a scheme for an intermediate report of a computed indicator at a specific site, having the minimum background information for assessing the quality of the results. It is not replacing a complete site characterization report, whereas it as to be intended as a recommendation to homogenize information especially for seismic network metadata.

The general structure of the intermediate report contains 4 main sections: the first one with general information, the last one with the resulting value of the indicator including uncertainty estimation and, in between the two, the description of the main parameters of the data acquisition and analysis.

In the following are the templates for the selected mandatory indicators: f0, Vs(z), Vs30, Depth of seismological and engineering bedrock, Surface geology, Soil class.

B1 - REPORT TEMPLATE for f0

B2. REPORT TEMPLATE for Velocity profile VS(z)

B3. REPORT TEMPLATE for Vs30

B4. REPORT TEMPLATE for GEOLOGY

B5. REPORT TEMPLATE for BEDROCK DEPTH

B6. REPORT TEMPLATE for SOIL CLASS (equivalent to GROUND TYPE or SITE CLASS)

7.1 B1. REPORT TEMPLATE for f0

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. DATA

[a]	[b]
Microtremor recordings	Earthquake recordings

3. EQUIPMENT

Sensor type (velocimeter, accelerometer, geophones, etc)
Sensor components (3C, vertical, horizontal)
Sensor cutoff frequencies [Hz]
Sensor Manufacturer
Recorder Manufacturer

4. INSTRUMENTAL SETTING

Dates of experiment [DD/MM/YY – DD/MM/YY]
duration of acquisition [min]
Location map
picture
ground-sensor coupling (Earth/asphalt/artificial)

Anthropogenic noise source (type/distance/direction)
Weather conditions (Sunny/windy/rain)
Urbanization (Dense/scattered/rural)

5. PROCESSING *[*list of examples of used techniques and related info for processing*]*

[a] - Noise

<table>
<tr><th>Acquisition</th><th>Processing (method)</th><th>Processing (parameters)</th></tr>
<tr><td rowspan="2">Single station</td><td>Horizontal-to-Vertical spectral ratio (H/V)</td><td rowspan="2">Signal length [s]:
Figure with H/V curve or ellipticity curve (mean ± 1std):
Software:</td></tr>
<tr><td>Rayleigh ellipticity from H/V</td></tr>
</table>

[b] - Earthquakes

<table>
<tr><th>Acquisition</th><th>Processing (method)</th><th>Processing (parameters)</th></tr>
<tr><td>Single station</td><td>H/V</td><td rowspan="2">Phase (P, S, Coda, S+coda):
Number of earthquakes:
Magnitude range:
Reference site location (Lat, Lon):
Software:
Figure with SSR or H/V curve (mean±1std)</td></tr>
<tr><td>Couple site and reference (including reference at downhole)</td><td>Standard spectral ratio (SSR)</td></tr>
<tr><td>Regional networks</td><td>Generalized Inversion / Spectral inversion techniques</td><td>Reference paper:
Number of stations:
number of events:
Figure with site transfer function (mean±1std)</td></tr>
</table>

6. RESULTS

f_0 [Hz]	value
± std [Hz] AND/OR frequency band (fmin and fmax) around the peak [Hz]	Uncertainty
Preferred direction of f_0 [deg]	
Selection criteria (SESAME criteria for H/V on noise, transfer function > 2 for H/V and SSR on earthquakes, other)	

Single parameter Quality index	Q1 value (SERA guidelines)

7.2 B2. REPORT TEMPLATE for Velocity profile VS(z)

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. DATA

[a] non-invasive (active and/or passive seismic methods)	**[b] invasive (measurement in boreholes)**
Active surface waves	Down-hole
Passive surface waves	Cross-hole
Surface- or body- wave tomography	PS-logging
Other	Other

3. EQUIPMENT

Sensor	**Invasive**	**non-invasive (passive)**	**non-invasive (active)**
Sensor type (velocimeter, accelerometer, geophones, etc)			
Sensor components (3C, vertical, horizontal)			
Sensor cutoff frequencies (Hz)			
Sensor Manufacturer			
Recorder Manufacturer			

4. INSTRUMENTAL SETTING

	Invasive	**non-invasive (passive)**	**non-invasive (active)**
Dates of experiment [DD/MM/YY – DD/MM/YY]			
ground-sensor coupling (Earth/asphalt/artificial)			
Anthropogenic noise source (type/distance/direction)			
Weather conditions (Sunny/windy/rain)			
Urbanization (Dense/scattered/rural)			
Location map			
picture of experiment			
Number of sensors, geophones			
min/max sensors/geophones spacing (horizontal or vertical)			
duration of acquisition [min]			
Source offsets range			
type of active source (explosive, hammer, Vibroseis, …)			
Number of boreholes			
Distance between boreholes			
Depth of borehole			

5. PROCESSING *[examples of used techniques and related info for processing]*

[a] - Invasive

Acquisition	**Processing (method)**	**Processing (parameters)**
Down-hole	P- and S-waves time arrival inversion (ASTM D7400-08, 2008)	number of measurement depths and depth interval: Stacking number: wave type (SH, SV, P): Figure with Vs, Vp profiles
Cross-hole	P- and S-waves time arrival direct modeling (ASTM D4428M-00 S, 2000)	
Suspension PS logging		number of measurement depths and depth interval: Figure with Vs, Vp profiles:

Other		

[b] - Non-Invasive

Acquisition	**Processing (method)**	**Processing (parameters)**
Active, Refraction		software
Active, array	Multichannel Analysis of Surface Waves (MASW)	Modes (Rayleigh and/or Love wave): Minimum & Maximum wavelength (fundamental mode) of the dispersion curves (DC) to be inverted [m]: Minimum & Maximum frequency: Software: Figure with DC curve measured and inverted: Figure with Vs inversion:
Passive, Array	F-K and variants, SPAC and variants, Cross-Correlation, Other	
H/V inversion	Diffuse Field Assumption Rayleigh wave ellipticity SH assumption	Phase (noise/earthquake coda/earthquake S-wave): Signal length[s]: Number of earthquakes: Software: Figure with H/V measured and inverted: Figure with Vs inversion:
Surface-wave inversion	Linearized inversion Stochastic inversion (Montecarlo, etc.)	Type of inversion (simple or joint): Software: Reference paper for inversion: Figure with Vs inversion:

7. RESULTS

V_S model (table)	for each layer: Depth top and bottom [m], V_S [m/s], Uncertainty where Uncertainty is: V_S_min and V_S_max [m/s] AND/OR ± std [m/s] AND/OR Set of representative Vs(z)
radius of interest [m]	radius of interest of the model used to infer the V_S model (i.e. array aperture if inferred from non-invasive measurements)
Single parameter Quality index	Q1 value (SERA Guidelines)

7.3 B3. REPORT TEMPLATE for Vs30

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. DATA

[a]	[b]	[c]	[d]	[e]
Geophysical measurements	Geotechnical measurements	DEM (Digital Elevation Model)	Geolog y	Hybrid models (e.g. geology-slope or geomorphic terrain-based proxy)

3. PROCESSING *[list of examples of used techniques and related info for processing]*

[a] Geophysical measurements

Acquisition	**Processing (method)**	**Processing (parameters)**
Vs(z) from any method (invasive or non-invasive)	Time averaged on measured Vs	Reference (report/paper/correlation to obtain VS30…): Used techniques to compute Vs-profile or Dispersion Curve: Software:
Dispersion curve in the Vs – wavelength plane	Approximation $V_{S30} \approx$ VR (λ= 40-45 m)	

[b] Geotechnical measurements

Acquisition	Processing (method)	Processing (parameters)
SPT, CPT, Cu, etc…	Correlation geotechnical parameters – V_{S30}	Reference (report/paper/correlation to obtain V_{S30}…): Software:

[c] DEM (Digital Elevation Model)

Acquisition	Processing (method)	Processing (parameters)
DEM	Correlation geomorphic terrain classification - V_{S30}	Cartography (reference): DEM Resolution: Slope Range: Slope: Reference (report/paper/correlation to obtain V_{S30}…): Software:

[d] - Geology

Acquisition	Processing (method)	Processing (parameters)
geological map	Correlation geologic units - V_{S30}	Cartography (reference): Scale: Sheet: Geologic/lithologic unit: Name, Age, Rock mass structure, Thickness Reference (report/paper/correlation to obtain V_{S30}…): Software:
stratigraphic log		Log Depth: STRATIGRAPHY VALUE (Table with: Top depth, Bottom depth, Unit description) Reference (report/paper/correlation to obtain V_{S30}…): Software:

4. RESULTS

V_{S30} [m/s]	time averaged over the top 30 m
± std [m/s]	variability estimate

AND/OR min and max V_{S30} [m/s]	
Single parameter Quality index	Q1 value (SERA Guidelines)

7.4 B4. REPORT TEMPLATE for GEOLOGY

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. DATA

[a]	[b]
Cartography (geological, DEM, lithological...)	Field survey

3. PROCESSING *[list of examples of used techniques and related info for processing]*

<table>
<tr><th>Acquisition</th><th>Processing (method)</th><th>Processing (parameters)</th></tr>
<tr><td>geological map (raster images, vector graphics)</td><td>Cartographic information</td><td rowspan="2">Cartography type (reference):
Scale:
Sheet:

Geologic/lithologic unit (Name, Description, Age, Rock mass structure, Thickness):
fault presence:
water table:
weathering:
cross-section:</td></tr>
<tr><td>Field survey</td><td>Cartographic information</td></tr>
<tr><td>DEM map (raster images, vector graphics)</td><td>Analysis of raster images</td><td>Cartography type (reference):
DEM Resolution:
Slope Range:
Slope:</td></tr>
<tr><td>stratigraphic log</td><td>geological unit interpretation</td><td>Log Depth:</td></tr>
</table>

		STRATIGRAPHY VALUE (Table with: Top depth, Bottom depth, Unit description)

4. RESULTS

Thematic map	Cartography type (e.g. geological lithotechnical, lithological......): Scale: Sheet: figure
Prevalent Geologic/lithologic unit description:	unit name and general description: Age: Thickness: Rock mass structure: stratigraphic log (if available):
Morphological description	Slope Range: Slope:
Single parameter Quality index	Q1 value (SERA Guidelines)

7.5 B5. REPORT TEMPLATE for BEDROCK DEPTH

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. TYPE

[1]	[2]
Seismological bedrock (depth of the impedance contrast related to the lowest resonance frequency peak)	Engineering bedrock (depth corresponding to a given Vs value according to the seismic codes)

3. DATA

[a]	[b]
non-invasive (active and/or passive seismic methods)	invasive (measurement in boreholes)

4. PROCESSING *[list of examples of used techniques and related info for processing]*

<table>
<tr><th>Acquisition</th><th>Processing (method)</th><th>Processing (parameters)</th></tr>
<tr><td>Down-hole, Cross-hole, etc</td><td rowspan="2">Vs-Vp profile/model</td><td rowspan="2">Figure with Vs, Vp profiles:
Reference (report/paper/…):
Used techniques to compute velocity profile:
Software:</td></tr>
<tr><td>MASW, seismic array, single-station H/V</td></tr>
<tr><td>Microtremor recordings, Earthquake recordings,</td><td>relationship of fundamental frequency f_0 - depth/thickness (for seismological bedrock only)</td><td>f_0:
Figure with site transfer function (mean±1std):</td></tr>
</table>

		Reference (report/paper/relationship to obtain depth/…):
geological information	inferred depth corresponding to a geological substratum	Figure with inferred Stratigraphic log: Reference (report/paper/relationship to obtain depth…):
stratigraphic log	relationship of lithology – seismic velocity profile	Figure with Stratigraphic log: Reference (report/paper/relationship to obtain depth…):
Other techniques (gravity, seismic refraction, TDEM, etc.)		

7. RESULTS

Bedrock Depth [m]	Depth of seismological or engineering or geological bedrock
± std [m] AND/OR min and max depth having Vs_bed [m]	Depth variability estimate
Vs_bed [m/s]	Vs of seismological/engineering bedrock
radius of interest [m]	radius of interest of the model used to infer the bedrock depth (i.e. array aperture if inferred from non-invasive measurements)
Reference building code for site classification	(EC8-1, EC8-2, national code, …)
Single parameter Quality index	Q1 value (SERA Guidelines)

7.6 B6. REPORT TEMPLATE for SOIL CLASS*

*equivalent to GROUND TYPE or SITE CLASS

1. GENERAL INFORMATION

Authors
Contacts (mail, Institution)
Link to reports, papers
Compiling date [DD/MM/YY]
Coordinates (WGS84) [Latitude, Longitude, Elevation]
Station name, Network code, Distance [m] of the closest seismological station, if any
Notes

2. DATA

[a]	[b]	[c]	[d]
Geophysical measurements	Geotechnical measurements	DEM (Digital Elevation Model)	Geolog y

3. PROCESSING [in this section we list examples of used techniques and related info for processing]

<table>
<tr><th>Acquisition</th><th>Processing (method)
from building code prescription</th><th>Processing (parameters)</th></tr>
<tr><td>Geophysical measurements</td><td>relationship of V_{S30} (from Vs profile) - soil class</td><td rowspan="4">V_{S30} value:
$H_{eng\_bedrock}$
f_0

Used DEM scale:

geologic units:
stratigraphy:

Reference of processing method (report/paper/relationship to obtain soil class …):
Software:</td></tr>
<tr><td>Geotechnical measurements</td><td>relationship of V_{S30} (from correlation with geotechnical parameters) - soil class</td></tr>
<tr><td>DEM (Digital Elevation Model)</td><td>relationship of V_{S30} (from correlation with geomorphic terrain) - soil class</td></tr>
<tr><td>Geology</td><td>relationship of V_{S30} (from correlation with geologic units) - soil class</td></tr>
</table>

4. RESULTS

Soil class	(A,B,...)
Reference building code for site classification	(EC8-1, EC8-2, NEHRP, national code, …)
Single parameter Quality index	Q1 value (SERA Guidelines)

Contact

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