BEST PRACTICE AND QUALITY ASSESSMENT PROCEDURES FOR SITE CHARACTERIZATION AT SEISMIC STATION: AN EUROPEAN INITIATIVE

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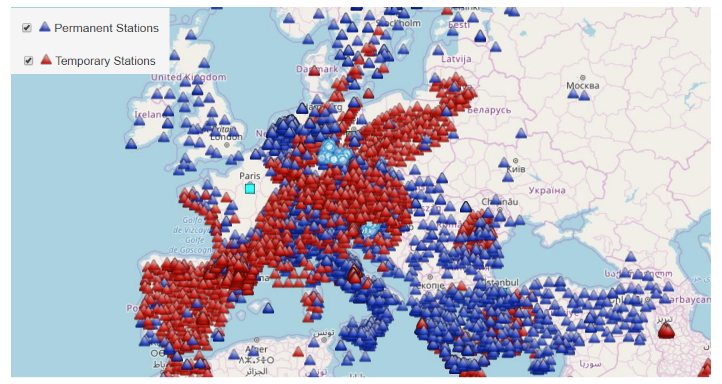
1 Introduction

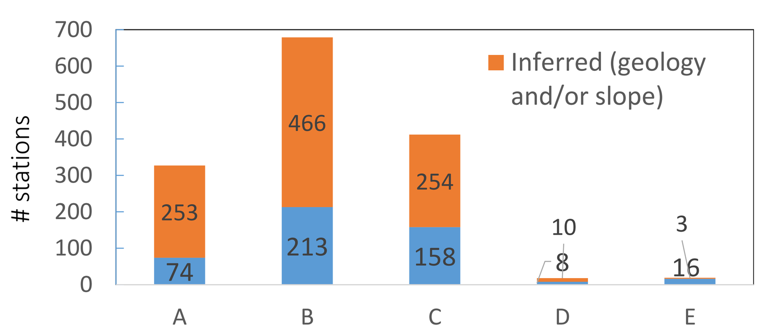
Seismic site characterization of soil properties at seismic stations has a large impact on earthquake ground motions and engineering seismology, especially for evaluation of local site amplification, calibration of strong-motion records and realistic shaking estimates, site-specific hazard assessment, estimation of ground motion models and soil classification for building code applications.



In recent years, the number of stations of permanent seismic networks worldwide is largely increased, rising the amount of earthquake signals and the applications using real-time recordings.

European Integrated Data Archive EIDA
https://www.orfeus-eu.org/data/eida/

However, there is not yet a common way to exchange site characterization information, whereas setting-up standard practices and quality assessment are becoming very important to reach high-level metadata.



Engineering Strong Motion (ESM) database (http://esm.mi.ingv.it; Luzi et al. 2016): distribution of strong motion stations as a function of EC8 site categories (CEN 2004). Out of 2071 permanent seismic stations, 70% have an EC8 soil class, but only 22% have a Vs30 measured with different methods. From Lanzano et al. (2019).

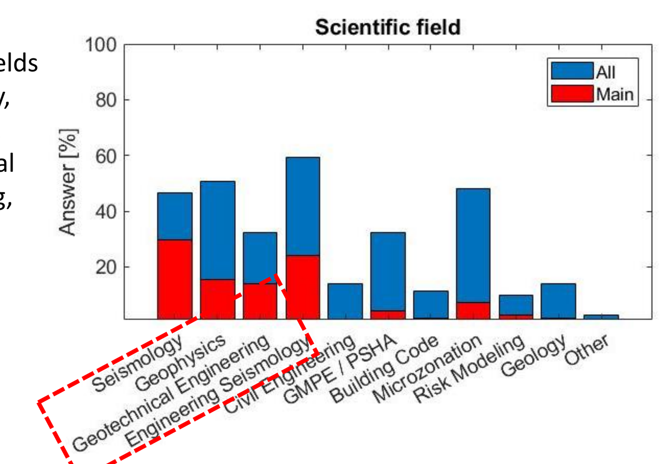
Within the framework of the SERA "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe" Horizon 2020 Project, a networking activity is leading to the definition of a European strategy and standards for site characterization of seismic stations in Europe (SERA-NA5, lead by C. Cornou). The standards, proposed by Task2 "Best practice and site characterization quality assessment", have been shared within European and worldwide scientific community and validated through focus groups during a dedicated workshop (https://sites.google.com/view/site-characterization-workshop/). They represent a first attempt to reach high-level metadata for site characterization, being aware that they can be improved and modified after a few years of experience and feedback from users.

2 A voting Questionnaire for consensus

Following a preliminary investigation, we defined a list of indicators for site effect characterization, for which we asked the opinion of a broad audience coming from different scientific fields. The investigation was carried out through an online Questionnaire sent to more than 300 collegues on different scientific fields.

✓ Answers from 71 team/researchers from different countries (69% Europe, 31% other countries)

✓ different scientific fields (seismology, geophysics, geotechnical engineering, etc.)

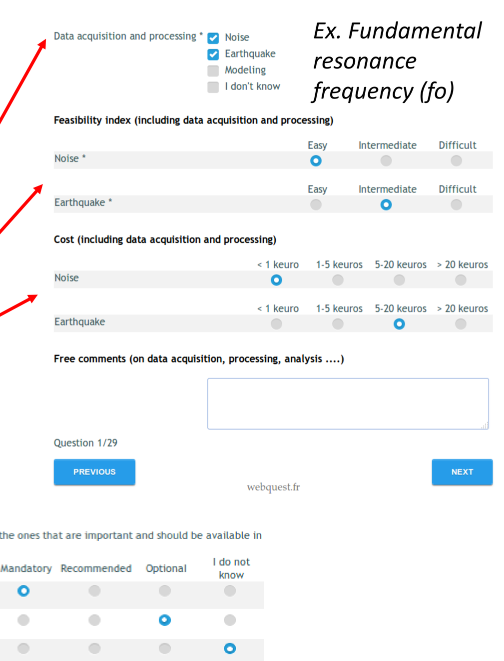


What we asked

We proposed a list of indicators for which we asked:

- ✓ the best method of estimation
- ✓ the feasibility index (level of difficulty for deriving it) → data acquisition and method of analysis
- ✓ the cost for deriving it

✓ Importance

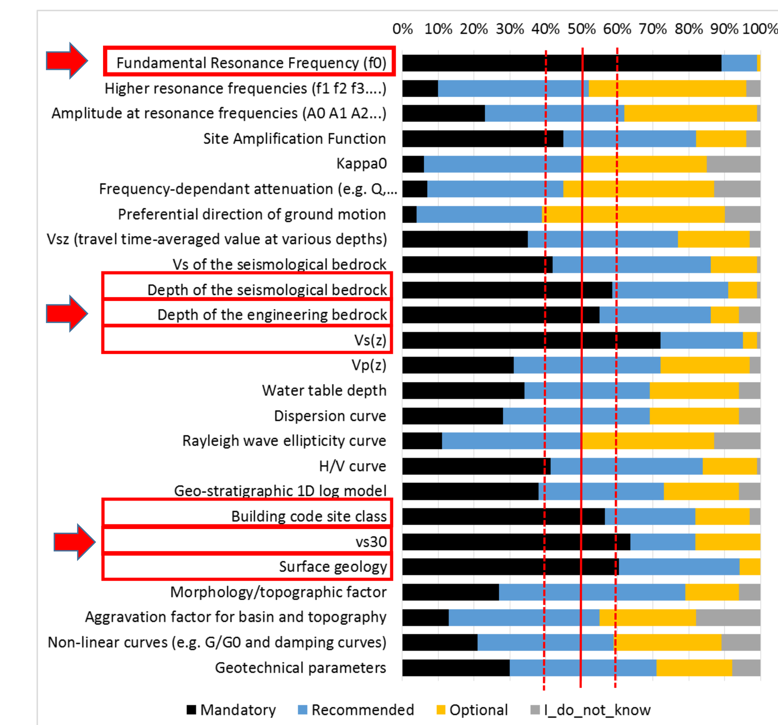


✓ Indicators list

f_0, f_1, ….fn and A_0, A_1,…A_n
Site Transfer Function (STF)
Preferential direction of ground motion
Duration Lengthening
kappa0
Frequency-dependent attenuation
V_{S30}, Vsz_below_30m, Vsz_above_30m
Vs and H of seismic bedrock
H_engineering_bedrock
$V_s(z)$, $V_p(z)$
dispersion curve, Rayleigh wave ellipticity
Building code Site Class (soil class)
Aggravation factor for basin and topography
Surface geology
Topographic factor, Geometrical parameter
geo-stratigraphic 1D log model
H_water_table
Non-linear degradation curves
Geotechnical parameter

Most recommended indicators

The results of the online questionnaire led to a list of indicators considered as mandatory or at least most recommended for a reliable site characterization and that should be available in strong motion databases.



Mandotory parameters > 50% of answers

✓ The majority of indicators are recommended for a reliable site characterization

✓ few of them are largely considered as mandatory:

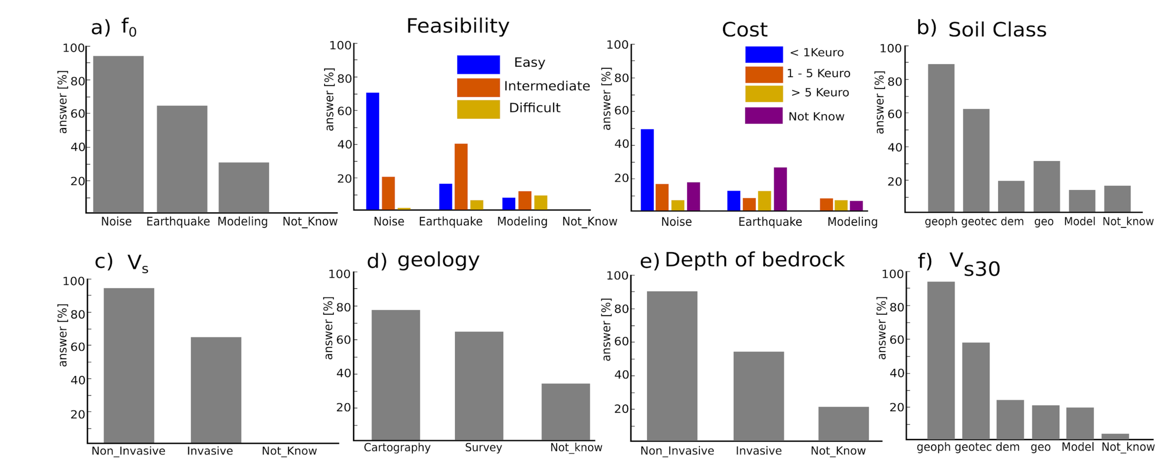
- fundamental resonance frequency (f0),
- average shear-wave velocity VS in the first 30 m of depth (VS30),
- seismic bedrock depth,
- engineering bedrock depth (corresponding to a Vs fixed in the Building code),
- Subsoil velocity profile of shear-wave as a function of the depth (Vs(z)),
- site class according to a specific Seismic Building Code,
- Geological and lithological information from available cartography and/or geological surveys

✓ Missing important parameters (12% YES):

- 1D/2D/3D effects, Uncertainties, Dependence to the earthquake location

Results

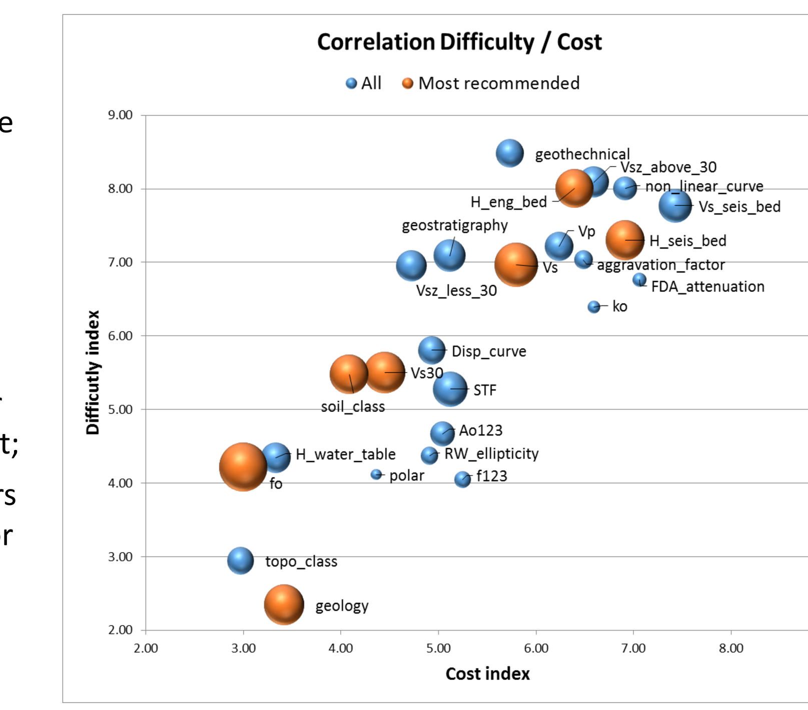
For each indicator, different data type/processing are chosen and, for each selection, 3 levels of feasibility (easy, intermediate and difficult) and 3 levels of cost (small, intermediate and high). For example, the best data acquisition and processing methods to compute f0 uses noise and earthquake data: it easier to compute it from noise and less expensive.



Histograms for the most appropriate indicators (grey). Feasibility and Cost are shown for f_0 indicator only.

For each indicators, both the average difficulty index and cost index are computed by weighting the individual feasibility and cost obtained for each method, scooting to the number of people recommending each method:

- ✓ the higher is the difficulty to infer the indicator, the larger is the cost;
- ✓ the most recommended indicators (orange) do not depend on cost or difficulty: the choice is related to the confidence on them.

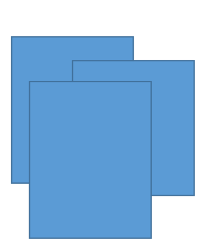


Size is proportional to number of recommendation for mandatory

3 Summary report

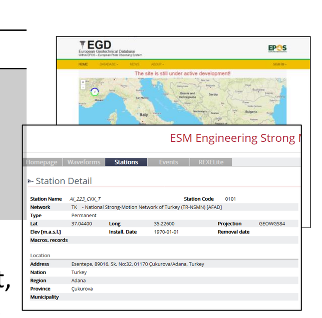
We then proposed a summary report for each recommended indicator, containing the most significant background information of data acquisition and processing details.

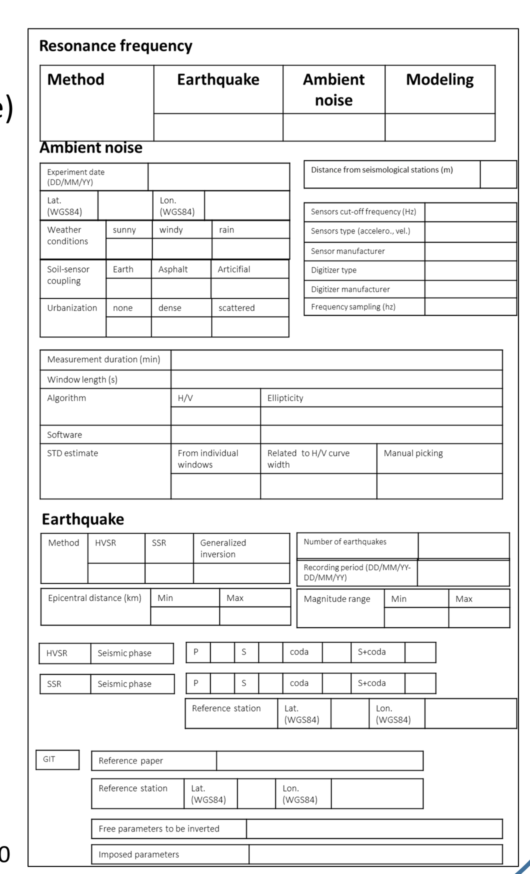
Complete reports → Summary report → Databases (indicator's value)



detailed description of methods, acquisition and processing

	Content
General	Authors, Contacts, Link to reports, papers; 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





Example of summary report for f0

REFERENCE
Di Giulio G., G. Cultrera, C. Cornou, P.-Y. Bard, B. Al Tfaily (2019). D7.2 - Best practice and quality assessment guidelines for site characterization Work package WP7: Networking databases of site and station characterization. Submission date 18.04.2019. http://www.sera-eu.org/export/sites/sera/home/.galleries/Deliverables/SERA_D7.2_Best-practice_for_site_characterization.pdf

4 Quality metrics

There is a need for an overall quality metrics to define level of reliability of the site characterization, to be included in seismic station metadata. This requires the evaluation of both (i) reliability of the indicators provided by different methods, and (ii) consistency among the results, according to the current knowledge and experience of the scientific community:

$$Final\_Q_{index} = \frac{Q_{index2}(Q^{i}_{index1}) + Q_{index3}}{2} \quad [0 \div 1]$$

Index 1: Quality of single indicator

$$Q_{index1} = \frac{[(a + b * c) * d]}{a_{max} + b_{max} * c_{max}} \quad [0 \div 1]$$

(a) Method of acquisition and analysis; (b) Direct measurement / inferred value; (c) processing; (d) Completeness of the report (If no report then = 0 !)

	Definition	Value	Explanation
a	Method of acquisition and analysis	1	peer-reviewed papers
		0	not published
b	Estimation of indicator	2	field experiments
		0	inferred values
c	Processing	1	robust
		0.5	partial confidence
		0	incorrect
d	Completeness of the report	1	well-documented
		0.5	Incomplete
		0	Not available

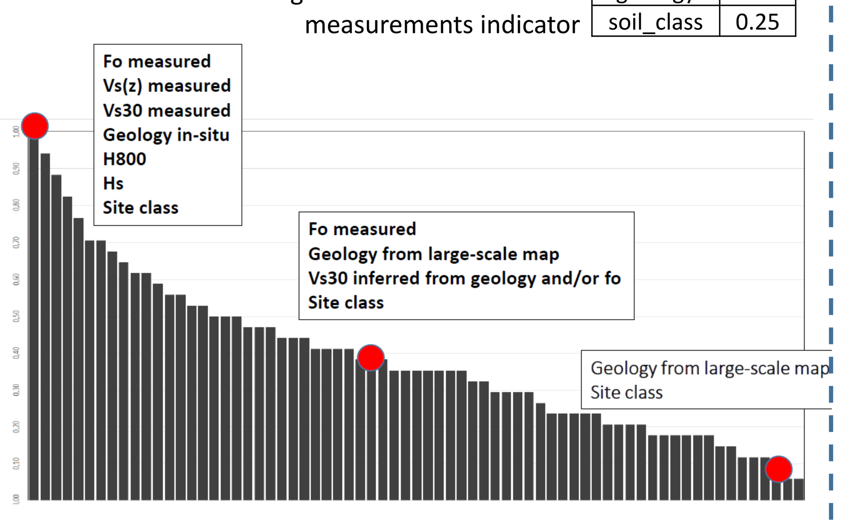
Index 2: Quality of a overall characterization

Weighted sum on Q_index1 of n=7 most appropriate indicators:

$$Q_{index2} = \frac{\sum_{i=1}^{n}[w_i * Q^{i}_{index1}]}{\sum_{i=1}^{n} w_i} \quad [0 \div 1]$$

Indicator	
fo	1
Vs(z)	1
Vs30	0.5
H_seis_bed	0.5
H_eng_bed	0.5
geology	0.5
soil_class	0.25

Weight is maximum for direct measurements indicator



To explain the sensitivity of Q_{index2}, we computed the Q_{Index1} for each indicator by using: a=1, b=2 for direct evaluation or b=0 for inferred values, c=1 and d=1. We then assumed to have a decreasing number of available indicators and we computed the Q_index2 for the site. Values are ranked from maximum value (all the indicators are computed and they have been measured directly) to the lowest (Vs30 or Geology indicators as proxies).

Index 3: Consistency of results

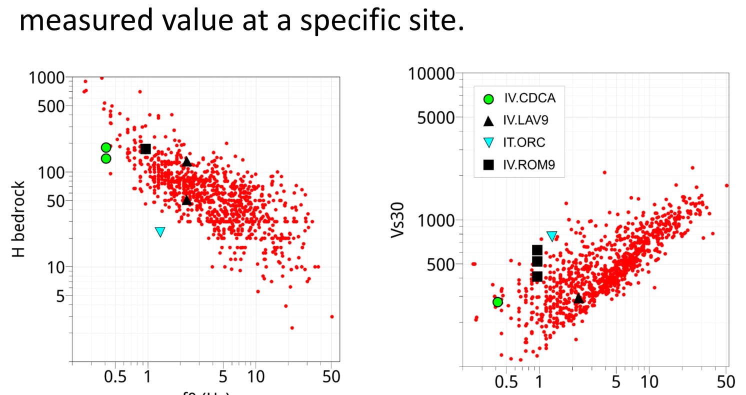
Quantification of the overall compatibility between the various indicator's value:

$$Q_{index3} = \frac{[\sum_{k=1}^{m} cons(k)]}{m} \quad [0 \div 1]$$

Where *cons(k)*=1 if consistent, 0 if not consistent, and *m=5* is the number of available couples of indicators for which published relationships references are available:

- k=1 (f_0 & V_{s30})
- k=2 (f_0 & seismic bed. depth)
- k=3 (f_0 & engineering bed depth)
- k=4 (V_{s30} & engineering bed. depth)
- k=5 (V_{s30} & geology)

The consistency can be assessed in case-study papers focused on deriving a specific indicator or through empirical relationships between various indicators. However, when there are not available studies, or in addition to, we propose a reference set of scatter plots to compare with the measured value at a specific site.

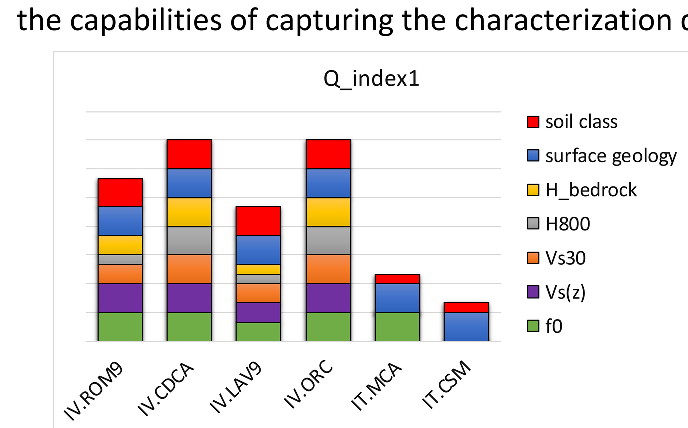


Scatter plot for couple of indicators: a) f0 - seismic bedrock depth (H bedrock in m), b) f0-Vs30 (in m/s). Red: simulated values; others: real values from selected Italian sites.

- ✓ We select 935 strong motion sites where real V_s profiles are available (602 Kiknet, 243 Californian, 21 European strong-motion, 33 French and 36 Italian).
- ✓ The indicators, except for Vs, are computed by using a 1D velocity model and processing homogeneously the resulting data: V_{s30}, site class, depth of engineering bedrock (H_{800}) and f_0 from the SH amplification (reflectivity method; Kennet, 1983); seismic bedrock depth for which the resonance frequency provided by the Rayleigh's method is similar to the measured f_0.

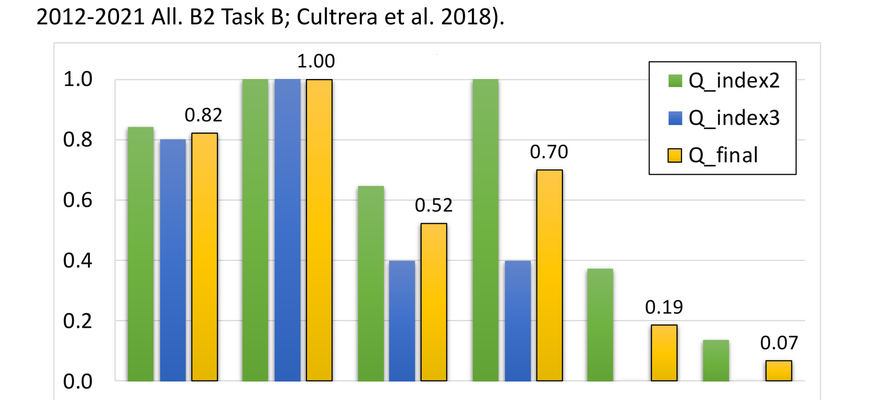
Examples

The quality metrics of some Italian accelerometric sites highlights the capabilities of capturing the characterization quality.



The information on the site characterization are available at the Italian Accelerometric Archive (ITACA; http://itaca.mi.ingv.it).

The IV sites were studied in the framework of a project for site characterization of permanent Accelerometric Italian Neworks (Italan Civil Protection Department, DPC, and INGV agreement 2012-2021 All. B2 Task B; Cultrera et al. 2018).



- ✓ CDCA and ORC: all the recommended indicators are well computed (Q_index1=1) but the measured values at ORC do not fit the scatter plot (Q_final=0.7);
- ✓ ROM9: as CDCA but Vs values from different methods are not consistent because of possible processing problem (lower Q_final=0.8);
- ✓ MCA and CSM: few indicators available, for none of them it is possible to assess consistency; Q_final is higher at MCA because of 3 indicators includinig f0.