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ORIGINAL ARTICLE

CRISP: an archive for the site characterization of permanent Italian seismic stations

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Abstract
In this paper we describe an advanced database for the site characterization of seismic stations, named “CRISP—Caratterizzazione della RIsposta sismica dei Siti Permanenti della rete sismica” (http://crisp.ingv.it, quoted with https://doi.org/10.13127/crisp), designed for the Italian National Seismic Network (Rete Sismica Nazionale, RSN, operated by Istituto Nazionale di Geofisica e Vulcanologia). For each site, CRISP collects easily accessible station information, such as position, type(s) of instrumentation, instrument housing, thematic map(s) and descriptive attributes (e.g., geological characteristics, etc.), seismic analysis of recordings, and available geophysical investigations (shear-wave velocity [V_S] profile, non-linear decay curve). The archive also provides key proxy indicators derived from the available data, such as the time-averaged shear-wave velocity of the upper 30 m from the surface (V_{S30}) and site and topographic classes according to the different seismic codes. Standardized procedures have been applied as motivated by the need for a homogenous set of information for all the stations. According to European Plate Observing System infrastructural objectives for the standardization of seismological data, CRISP is integrated into pre-existing INGV instrument infrastructures, shares content with the Italian Accelerometric Archive, and complies map information about the stations, as well as local geology, through web services managed by Istituto Superiore per la Protezione e la Ricerca Ambientale. The design of the CRISP archive allows the database to be continually updated and expanded whenever new data are available from the scientific community, such as the ones related to new seismic stations, map information, geophysical surveys, and seismological analyses.

Keywords Site effects · Site characterization · Permanent seismic station · Italian National Seismic Network · Database

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1 Introduction

The number of stations belonging to the permanent seismic networks worldwide has largely increased over the years, significantly increasing the amount of recorded data (Cauzzi et al. 2021 and references therein). Unfortunately, most of the existing strong motion databases do not include sufficient information on the site characterization, even though the recordings can be significantly affected by the variation of subsoil geological structure. This issue can be critical for studies based on earthquake ground motions: a recent European project (2017-20 SERA-Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe, EU Project no. 730900, Horizon2020 INFRAIA-01-2016–2017 Program; http://www.sera-eu.org/, last accessed 10-10-2022) identified the most relevant indicators for site characterization at seismic stations to be used for its quality evaluation, with the aim of homogenizing site metadata information at European level and defining the reliability of the site characterization (Cultrera et al. 2021; Giulio et al. 2021). SERA project also performed a thoughtful analysis on the available information at European permanent strong motion sites and identified priorities and key issues in terms of future needings and perspectives, from the point of view of both network operators and end-users (Cornou and Bard 2019). For instance, in the last few years, some actions were launched at the European level to disseminate site information of permanent and temporary seismological stations, as: (i) the Earthquake Strong Motion database (ESM, https://esm-db.eu/, last accessed 10-10-2022; Luzi et al. 2016, Luzi et al. 2020); (ii) the ORFEUS station book (Observatories and Research Facilities for European Seismology, http://orfeus-eu.org/stationbook/, last accessed 10-10-2022); (iii) the European Geotechnical Database (EGD, http://egd-epos.civil.auth.gr/, last accessed 10-10-2022). As an example, ESM displays few-to-several indicators for site characterization of strong motion stations, but the direct measurements of the site attributes are most often either unavailable or have not yet been performed: in ESM 469 stations only (22% of the total number of stations) have EC8 soil class derived from measured V_S profiles, for the remaining stations being inferred from geology or terrain slope (Lanzano et al. 2019). At the same time, several efforts at national levels to perform site characterization have been carried out (e.g. Sandikkaya et al. 2010; Michel et al. 2014; Stewart et al. 2014; Albarello et al. 2017; Felicetta et al. 2017; Hollender et al. 2018), but a few seismological seismic networks are accompanied with detailed information and reports on site topography, morphology, geology and on seismic surveys used to derive shear-wave velocity profiles (Cornou and Bard 2019). This is the case of the ITalian ACcelerometric Archive (ITACA, http://itaca.mi.ingv.it, last accessed 10-10-2022; D'Amico et al. 2021, Russo et al. 2022) that displays few-to-several indicators for site characterization, or of Switzerland (http://stations.seismo.ethz.ch, last accessed 10-10-2022) and Turkey (http://kyhdata.deprem.gov.tr, last accessed 10-10-2022) archives. Unfortunately, many monitoring stations equipped with only velocimeters lack site metadata.

Other efforts are mainly dedicated to the measurement and collection of the V_S information. They are frequently published as a flat-file (Xie et al. 2022; Cho et al. 2022) with the exception of the Shear-wave Velocity Profile Database (VSPDB https://vspdb.org, last accessed 10-10-2022), that includes geophysical data for many seismic stations in North America, Japan and for some other countries (Seyhan et al. 2014, Yong et al. 2016, Ahdi et al. 2017, McPhilips et al. 2020), and was recently adapted to account for the results of Horizontal-to-Vertical spectral ratio on noise (Wang et al. 2021).

In Italy, INGV is in charge of the earthquake monitoring (Michelini et al. 2016; Margheriti et al. 2021) and manages most of the stations through the Italian seismic network (Rete

Sismica Nazionale, RSN). By the end of 2020, it consisted of 449 stations scattered throughout the national territory: 165 equipped with both velocimetric and accelerometric sensors, 249 with velocimeter only, 35 with accelerometer only. The information on the RSN instrumentation is stored on an internal database that contains instrumental parameters and the history of maintenance interventions (SeisNet; Pintore et al. 2012). Such information is used by INGV network operators to build the dataless files that, together with the continuous signals transmitted by the RSN stations, are archived and distributed through the INGV node of the European Integrated Data Archive (EIDA; http://eida.ingv.it, last accessed 10-10-2022; Danecek et al. 2021). Other details on installed stations are indeed scattered in personal archives and often not easily accessible by the scientific community.

The great effort for the realization of platforms and portals for station management and data distribution did not include the collection of site information of the entire RSN stations, despite sparse efforts to characterize some RSN sites for research purposes (Pischiutta 2010; Pischiutta et al. 2011; Ladina et al. 2013; Massa et al. 2014; Pischiutta et al. 2018; Felicetta et al. 2021) or in the framework of the agreement between the Italian Civil Protection Department (DPC) and INGV since 2016 (herein after "DPC-INGV agreement").

To fill this gap, INGV promoted an articulated program based on activities that involved different skills: seismology, geology, geotechnical and earthquake engineering, and computer science. The targets of these activities were: (i) identification of as many indicators as possible for site characterization to be used for its quality evaluation, at national (already mentioned DPC-INGV agreement) and international level (SERA project; Cultrera et al. 2021, and Giulio et al. 2021); (ii) definition of a common practice for site characterization of seismic stations; (iii) promotion of internal, national and international projects on these issues; (iv) systematic collection of the site information.

The result of these joint efforts was the creation of a site characterization database of the RSN network, that we present in this paper. The CRISP archive (acronym for "Caratterizzazione della RIsposta sismica dei Siti Permanenti della rete sismica"—Site characterization of the permanent seismic stations, http://crisp.ingv.it, last accessed 10-10-2022*;* Cultrera et al. 2022) brings together all the information related to RSN sites. For each site, CRISP collects metadata about the position, instrumentation, instrument housing (for possible site-structure interaction), thematic map, geological characteristics, seismic analysis and geophysical investigation for site response quantification. It also provides proxy indicators derived from the available data, such as the time averaged shear-wave velocity of the upper 30 m from the surface (V_{S30}), and site and topographic classes according to the national seismic code.

With respect to other Italian databases that provide site information, CRISP refers to all the RSN sites instrumented with velocimetric or accelerometric or both sensors, and includes a very large number of indicators and analyses collected all together to be used for a complete site-response evaluation of the site. It also retrieved all available data of the station sites collected by the network operators.

In the following we describe the design, the functionalities and the contents stored and available through the database.

2 Database model and back-end

CRISP is a specific relational database model structured to represent information relating to site characterization parameters and seismic stations metadata. It is the result of in-depth discussion in a large group of experts on related topics: geologists, seismologists, engineers, IT specialists.

The model was designed by using an Unified Modeling Language (UML) diagram represented in Fig. 1 (the complete diagram figure is in the Online Resource 1). The main entity directly refers to the seismic station parameters, whereas the principal entities about site characterization are either referred directly to the station or they can exist independently. All information contained within CRISP is directly related to specific geographical coordinates which refer to the sites of existing seismic stations. However, it is possible to enter parameters relating to site coordinates not necessarily linked to an existing seismic station. Several attributes are detailed with enumerative values. The multiplicity relationships are displayed along the lines that connect the different entities. So for example, we can have for a *Site* at most only one *InstrumentHousing*, and for a *InstrumentHousing* we can have no or more *NoiseSource*.

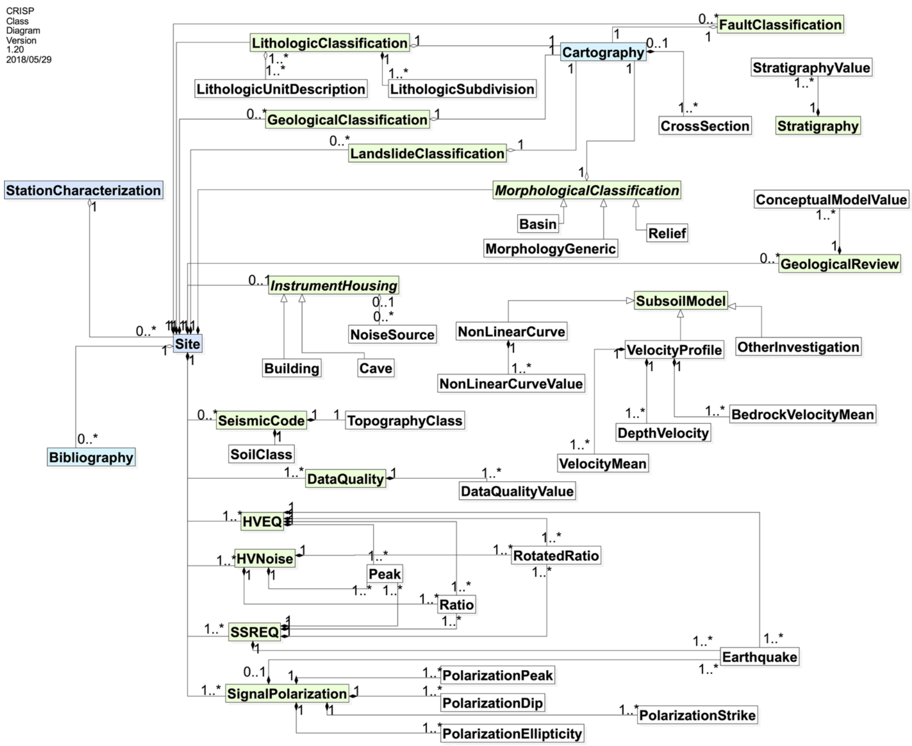


Fig. 1 A brief version of UML diagram (entity-relation) of the CRISP database. Light blue: main entities directly referring to the seismic station; green: principal entities about site characterization; white: detailed entities linked to the principal ones. The lists of the attributes of single entities can be found in the complete UML diagram in the Online Resource 1. The User manual, available on the CRISP website (http://crisp.ingv.it/info_attachments/index, last accessed 10-10-2022), contains the detailed description of each field

The physical database was implemented by the DBMS PostgreSQL/PostGIS which is integrated in a web application with GIS functionality (Geographical Information System). It is provided with procedures and scripts for database population, RESTful web services for the automated extraction and distribution of information, and a storage for auxiliary data. External procedures and scripts allow to massively populate and update specific fields.

Relations with other on-line archives enable an exhaustive completion of the information contained in the CRISP database: it is integrated into the pre-existing INGV infrastructures (SeisNet) and exchanges information with the accelerometric databases (ITACA, ESM), according to European Plate Observing System EPOS infrastructural objectives for a correct use of the seismological data (https://www.epos-eu.org/, last accessed 10-10-2022). Finally, it is also able to store the further maps around the stations and information on the local geology through web services managed by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA; https://www.isprambiente.gov.it/, last accessed 10-10-2022).

Web services were also set up for exporting to other systems in JSON or text format through APIs (Application Programs Interface) that allow applications to access data and interact with external software components, operating systems, or microservices.

The web interface is developed in PHP language through Laravel framework, allowing textual and geographical visualization, querying and updating based on the different authentication levels. The website based on NGINX (https://www.nginx.com/, last accessed 10-10-2022) is freely available for all users and accessible without authentication; restricted access is only for site administrator and maintenance. CRISP is available in English language but it is also designed for internationalization.

The structure is designed in such a way that, with little programming effort, fields can be easily added if a new site proxy is considered, or if more information becomes necessary.

3 Front-end

In the following we describe the database frontend and we detail how the web pages are organized; moreover, in the next chapter we summarize the data presently available and the used methodologies to infer them. The detailed description of each field of the database can be found in the User manual (in about/documentation from menu bar: http://crisp.ingv.it/info_attachments/index, last accessed 10-10-2022), as well as the source and data analysis stored in the database.

The Homepage of the website (Fig. 2) provides a station list with a map of all the archived stations, together with a Menu bar at the top. The *Sites* item accesses the site list (*List*) and includes the possibility to query the database (*Search*) on different fields, returning the list of selected stations that can be downloaded in csv format, as described later on in this section. The other items in the Menu bar allows the users to browse the information categories existing independently of the site (*Bibliographies*, *Cross Section*, *Subsoil Model*, *Cartography*, *Stratigraphy*): *Bibliographies* item lists all the references used in the subsections, while the other categories, being georeferenced, can be linked to one or more sites on the database. The *About* item includes *Credits* and *Documentation*, such as the description of specific data analyses and the user's manual, where all database fields are described.

Every single site is browsing by clicking on button *details*. The Site page organizes its content with site position and map, instrument characteristics, geological information,

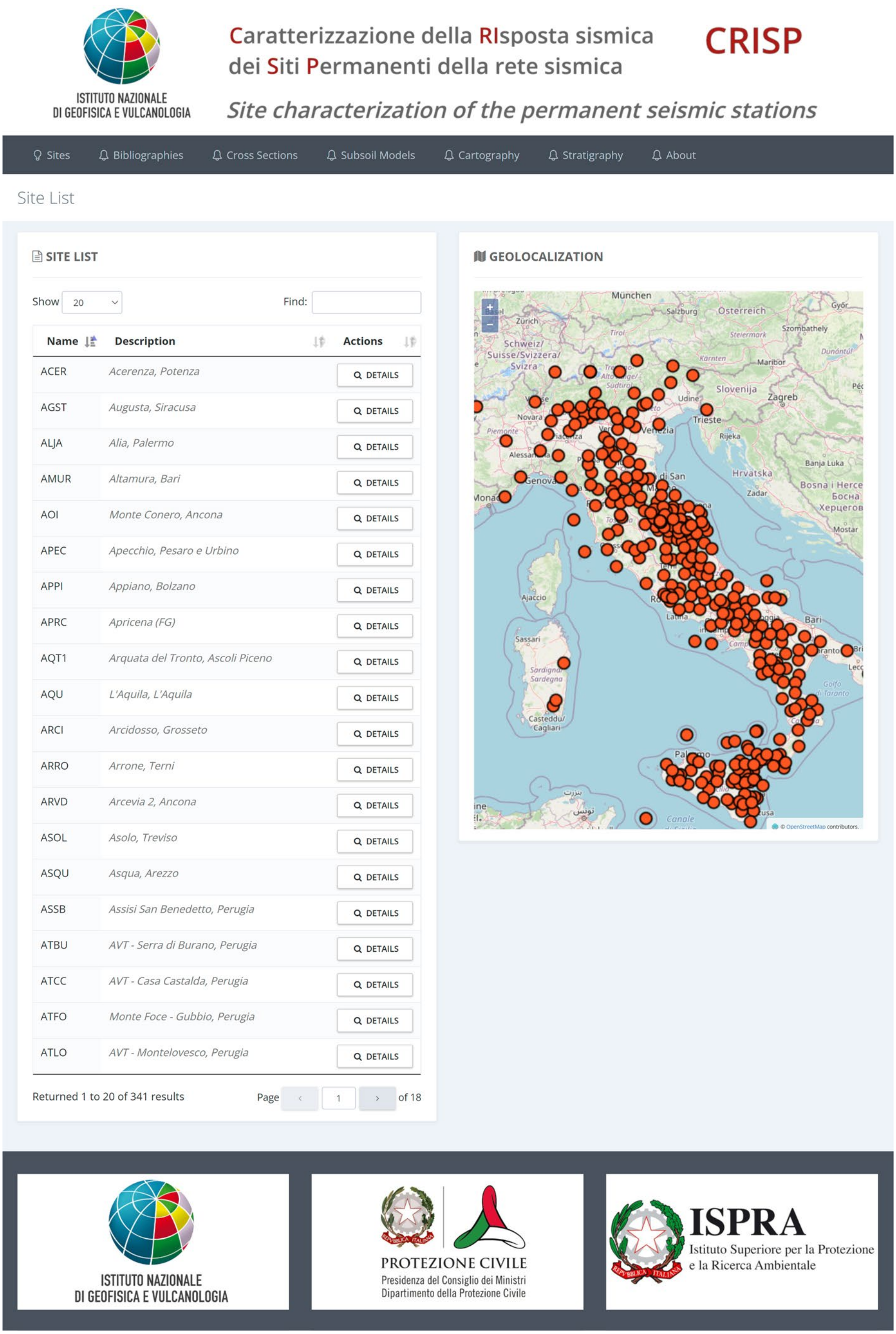


Fig.2 CRISP home page

seismological analysis, geophysical and geotechnical investigation (see Online Resource 2 for an example of the whole Site page). All information is split up into five principal sections, which are described afterwards: *Housing*, *Geology*, *Seismology*, *Geophysics*, and *Site classification*.

The Site page displays the principal fields, whereas detailed information can be accessed with the magnifying glass icon. All these subsections can store information coming from different approaches and specific studies, that is they can list multiple records representing a different type of analysis or approach.

Tooltips are present to explain some field contents or to refer to the online documentations (*i* symbol). The "*last update*" field allows you to recognize the entry date of the record, while the "*preferred*" field indicates the operator's preference with respect to the available data type.

3.1 Site setting/location

The panel at the top of the Site page (Online Resource 2) includes information about geographical localization and instrumentation details (Fig. 3). Although these data refer directly to the RSN seismic stations in the SeisNet database (Pintore et al. 2012), it is still possible to insert new independent sites, as the station coordinates are the database primary key.

The map box to the right side is 5 km × 5 km large (Fig. 3), showing the site position on a topographic map (©OpenStreetMap contributors) together with any other geological or geophysical surveys stored in the archive within 5 km distance from site, such as stratigraphy, cross section, subsoil model, etc. Investigations near the site are displayed by ticking the checkboxes below the map box. It is also possible to select maps archived as georeferenced images and KMZ/KML files, or retrieved by web services available (i.e. from ISPRA). The maps can be queried by clicking on it, and a box with detailed information on the geological and lithological outcrops appears.

The whole cartography list is also available by browsing the Menu bar *Cartography*.

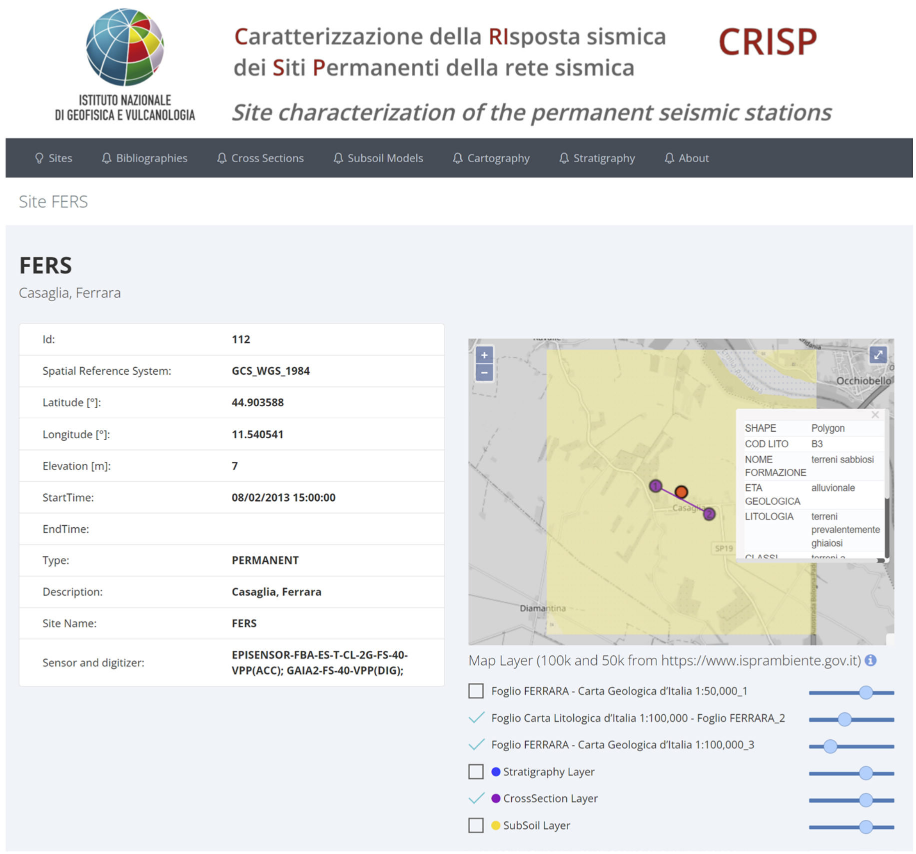


Fig. 3 Site section with setting and location information for IV.FERS (Casaglia, Ferrara): to the left side details on position and instrumentation, to the right side a box 5×5 km^2 with the station position (red circle) and any other geological or geophysical surveys stored in the CRISP archive within a 5 km distance from site, as stratigraphies (blue circle), cross sections (purple circle connected with line), subsoil models (yellow circle). Any other maps, archived in CRISP and within the box coordinates, can be displayed; the map transparency degree can be selected by using the blu bar to the right, and a box with outcrop information appears by clicking on the map

3.2 Housing

The Housing section contains information on instrument housing and quality estimation of data recorded by the seismic station (Online Resource 2).

The *Instrument housing* subsection is dedicated to the installation setup of the station and information about the surrounding environment: sensor-to-ground coupling, insulating, housing, notes and pictures, specific information on cave, building, and noise source (Fig. 4a). This part is useful for the evaluation of possible soil-to-structure interaction and peculiarities of the site installation.

The *Data Quality* subsection archives the results of the analysis on annual noise to evaluate the reliability of the recorded data in terms of noise level and instrument performance for detection of seismic events (Fig. 4b). The analysis is performed by calculating

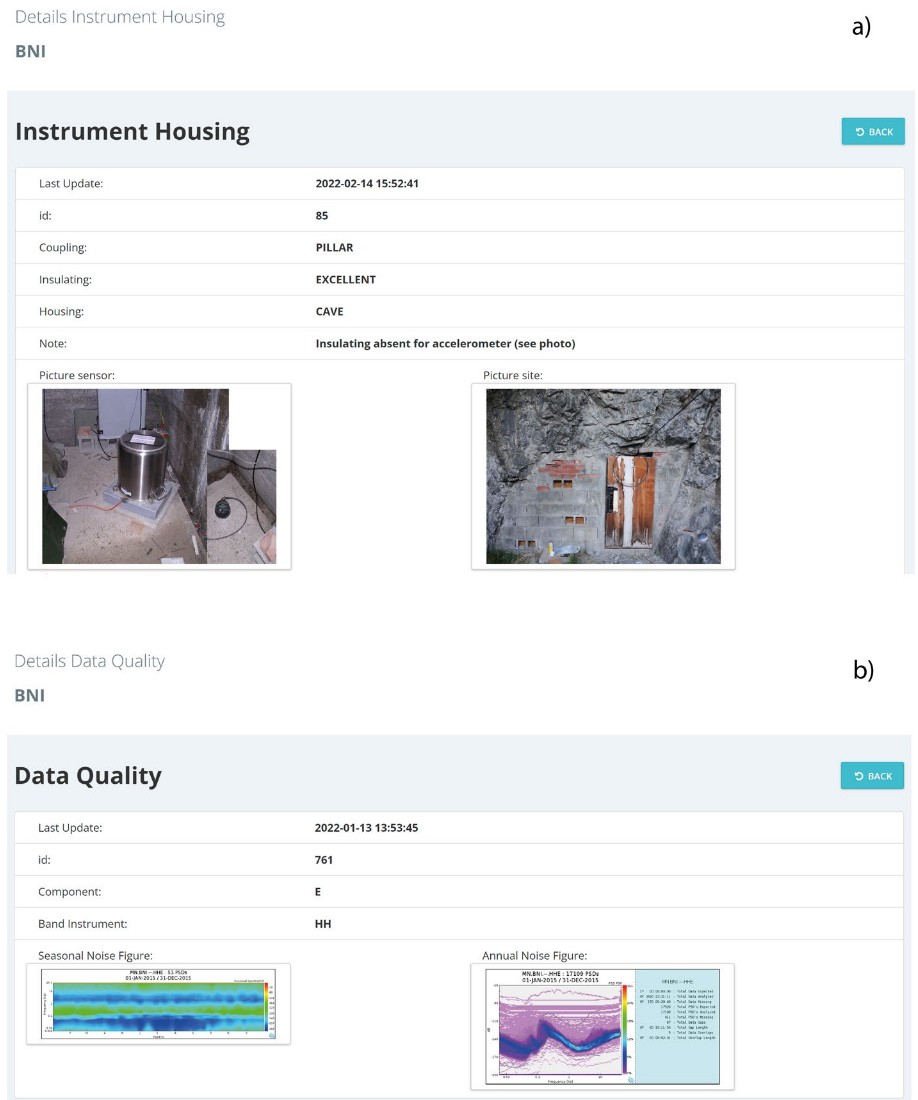


Fig. 4 Subsection details on Housing section for IV.BNI (Bardonecchia, Torino): details for **a** instrument housing and **b** data quality

the distribution of Power Spectral Density (PSD) as a function of frequency and using the Probability Density Function (PDF) (McNamara and Buland 2004; Marzorati and Lauciani 2015) to generate the plot that displays the distribution of the PSD. These results are useful both for estimating the noise level of the site and for highlighting possible anomalous behavior of the recorded data.

Two figures are stored for each component: the first is the Seasonal spectrogram showing, in a color scale, the level of noise as a function of the frequency and months of the year; the second is the annual noise figure showing each individual PSD curve computed using one-hour of data as a function of frequency, together with the Peterson (1993) reference curves where the color scale indicates the PDF in percentage. Data quality values (in terms of mode, 10th and 90th percentile of PSD at the selected frequencies) are visible in a separate and downloadable table.

3.3 Geology

Geology section contains the information on geology organized in thematic subsections (Online Resource 2): *Stratigraphy, Geological review, Morphological classification, Lithological classification, Geological classification, Fault classification, Landslide classification, Cross section.*

In the following we describe the thematic geological subsections.

Stratigraphy contains the punctual stratigraphic information, derived from well logs and continuous cores. Available data may come from several sources, such as ISPRA (https://www.isprambiente.gov.it/en/databases/data-base-collection/soil-and-territory/geognostic-and-geophysical-data, last accessed 10–10-2022), seismic microzonation studies (https://www.webms.it/, last accessed 10-10-2022) or geognostic investigations performed to characterize station sites. The site georeferenced stratigraphies are visible on the map box of the site within 5 km (blu dot on Fig. 3). Moreover, the list of all stratigraphic logs associated with different stations can be viewed using the *Stratigraphy* Menu bar.

Geological review includes downloadable monographs that summarize the geological, tectonic and stratigraphic characteristics of the station site. The proposed conceptual lithostratigraphic model for the station site can be viewed in tabular form.

Morphological classification contains the descriptive attributes resulting from morphological analysis based on Digital Elevation Models (DEM), topographic maps, satellite

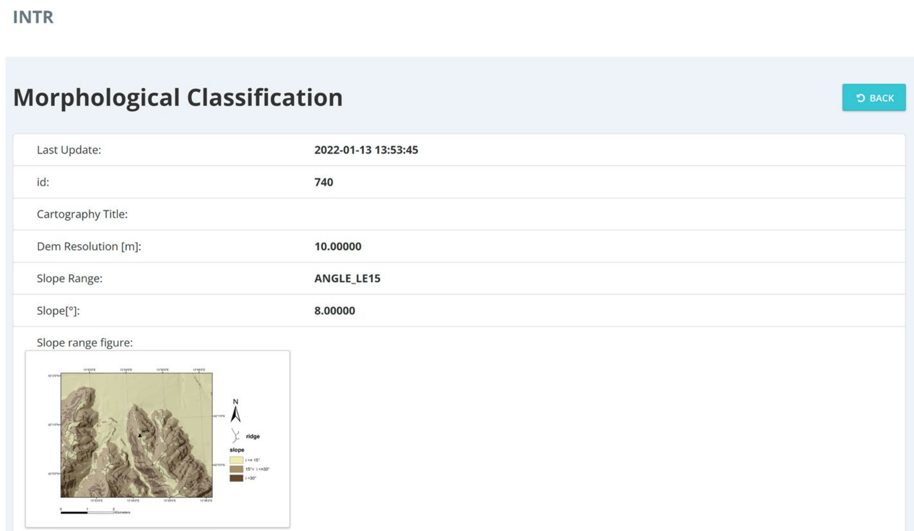
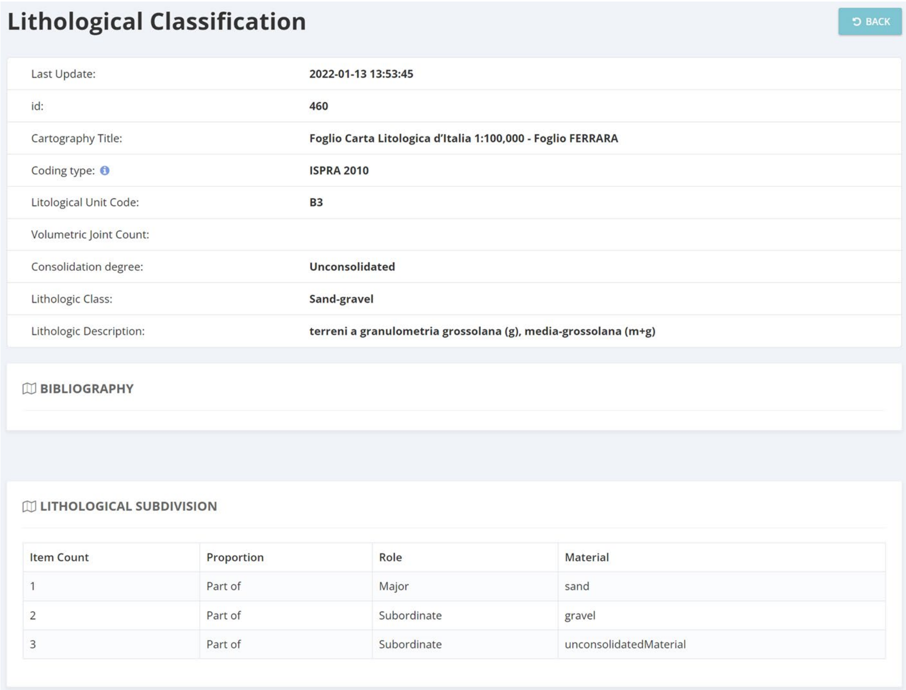


Fig. 5 Morphological classification subsection for DEM resolution of 10 m at IV.INTR (Introdacqua, L'Aquila)



Lithological Classification

BACK

Last Update:	2022-01-13 13:53:45
id:	460
Cartography Title:	Foglio Carta Litologica d'Italia 1:100,000 - Foglio FERRARA
Coding type:	ISPRA 2010
Litological Unit Code:	B3
Volumetric Joint Count:	
Consolidation degree:	Unconsolidated
Lithologic Class:	Sand-gravel
Lithologic Description:	terreni a granulometria grossolana (g), media-grossolana (m+g)

BIBLIOGRAPHY

LITHOLOGICAL SUBDIVISION

Item Count	Proportion	Role	Material
1	Part of	Major	sand
2	Part of	Subordinate	gravel
3	Part of	Subordinate	unconsolidatedMaterial

Fig. 6 Lithological classification subsection at IV. FERS (Casaglia, Ferrara)

and aerial photos or otherwise obtained from scientific literature. Morphological classification type is divided into two categories representative of the site conditions: Basin (including valleys, basins, plains, terraces, fans) and Relief (describing the topographical variations). Such information can be obtained by photo-interpretation of aerial and satellite images, including cloud-based geospatial platforms such as Google Earth. This subsection also includes a geomorphological map from spatial analysis (Fig. 5), as well as additional attributes for Basin and Relief morphological types.

Lithological and Geological classification consists of detailed descriptive attributes of the outcropping lithological and geological units under the site. Attributes are derived from the authoritative national repositories, such as the database of the geological map of Italy in scale 1:100,000 (Fig. 6) managed by ISPRA (https://www.isprambiente.gov.it/en/services/cartography/geological-and-geothematic-maps, last accessed 10-10-2022).

Descriptive attributes and the lithological terminology used are in agreement with the Infrastructure for Spatial Information in Europe (INSPIRE) directive. The contents of this subsection may also be compiled using data derived from surveys carried out for the characterization of the station sites, also according to the national standards of classification and representation used for Seismic Microzonation studies.

Fault classification contains the information about the existence of faults nearby at a definite distance, without considering their kinematic or activity. Values come from published sources such as geological maps, tectonic maps, fault databases (e.g. ITaly HAZards for CApable faulting catalog—ITHACA, ITHACA Working Group 2019; Database

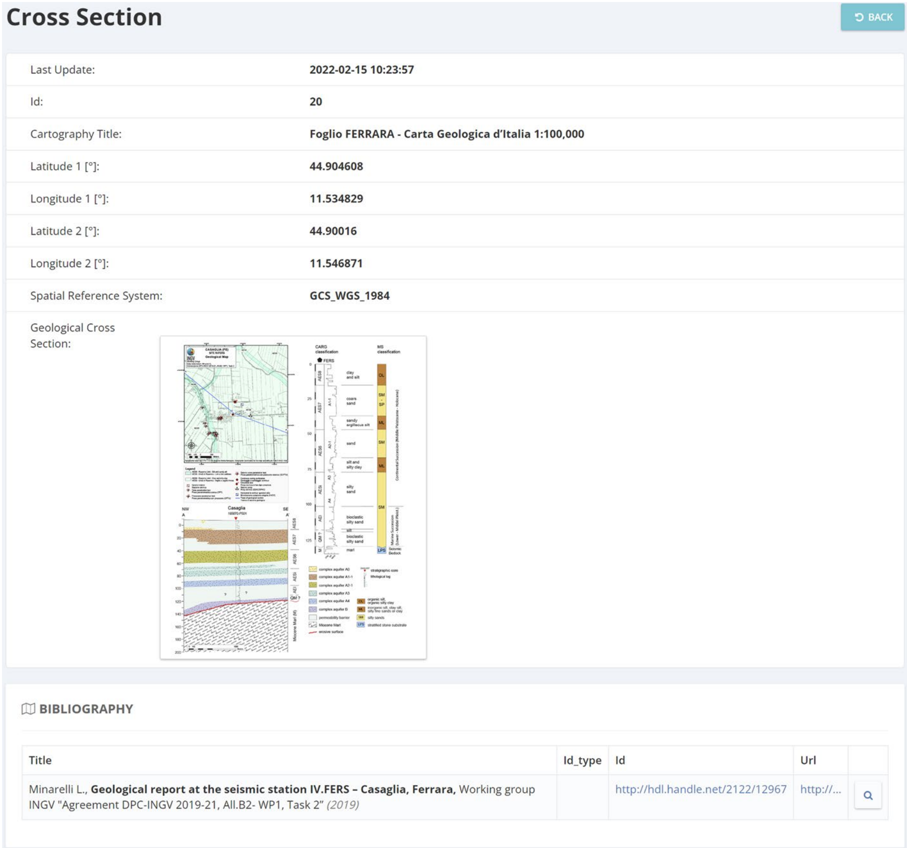


Fig. 7 Cross section details at IV.FERS (Casaglia, Ferrara)

of Individual Seismogenic Source—DISS, DISS Working Group 2021) or from scientific papers.

Landslide classification includes information about the existence of landslides, together with the distance from the site and the state of activity. They are inferred from published sources such as Italian Landslide Inventory (IFFI Inventory; https://www.progettoiffi.isprambiente.it/en/inventory/, last accessed 10-10-2022), regional hydrogeologic management plans or geomorphological-geological maps and Seismic Microzonation studies.

Cross section contains geographical coordinates and graphic representation of geological cross sections available for the station site (Fig. 7). The cross section shows the stratigraphic setting and the geometric relationships of the geological or lithological units of the area. A list of cross sections associated with different stations can be viewed using the *Cross Sections* Menu bar.

3.4 Seismology

Seismology section collects data analyzes useful to characterize the site using the station recordings. It is split up in the following four subsections (Online Resource 2): *HVEQ*

Fig. 8 Subsection details of Seismology section for IV.GUAR (Guarcino, Frosinone): **a** HVNOISE and **b** Signal Polarization

(Horizontal to Vertical spectral ratio on earthquakes), *HVNOISE* (Horizontal to Vertical spectral ratio on noise), *SSREQ* (spectral ratio using a reference station on earthquakes), *SIGNAL POLARIZATION* (signal polarization on earthquake or noise).

In the following we describe the thematic subsections.

HVEQ contains the analysis results of horizontal-to-vertical spectral ratio on earthquakes recorded by the station close to the site. Information on frequency range, band instrument, pictures of ratio and rotated ratio, number of peaks where amplitude is greater than 2 and earthquakes number are present. It is possible to visualize and download data files and figures on mean amplitude and rotated ratio as a function of frequency, peaks details (frequency and its amplitude, frequency range of amplification, direction of maximum amplitude), earthquakes information and any notes from the operator.

HVNOISE includes the analysis results of horizontal-to-vertical spectral ratio calculated using ambient noise recorded by the station close to the site (Fig. 8a). Information on analyzed lapse time, noise variability type, frequency range, band instrument, pictures of ratio and rotated ratio, number of peaks where amplitude is greater than 2 are present. It is possible to visualize and download data files and figures on ratio amplitude and rotated ratio as a function of frequency, peak details (frequency and its amplitude, frequency range of amplification, direction of maximum amplitude) and any notes from the operator.

SSREQ contains the analysis results of the spectral ratio with respect to a rock outcrop reference site. Information is given about: reference site and its geographical position, frequency range, component of the motion, band instrument, pictures of ratio and rotated ratio, number of peaks where amplitude is greater than 2 and earthquakes number. It is also possible to visualize and download data files and pictures on ratio amplitude and rotated ratio as a function of frequency, peak details (frequency and its amplitude, frequency range of amplification, direction of maximum amplitude) and any notes from the operator.

Signal polarization contains the analysis results of directional polarization of noise or earthquake seismic signal (Fig. 8b). Information on analysis type (noise or earthquake), signal time lapse, frequency range, band instrument, pictures on ellipticity, dip and strike, frequency peaks and earthquake number are available. It is also possible to visualize and download pictures and detailed information on polarization files, direction of principal axis, ellipticity, dip angle, and frequency peaks.

3.5 Geophysics

This section contains information on geophysical and geotechnical surveys performed near the site in order to define the subsoil model (Online Resource 2): model type (velocity profile, non linear curve, other), investigation type, preferred model, and site position. The information tip in the investigation type describes the acronyms' meanings. It is also possible to browse the whole subsoil model list using the Menu bar *Subsoil Model*.

In the following we describe the thematic subsections.

Velocity profile provides details on investigation type to infer it, distance from the site, survey date, compiler's notes, figure, monography, and specific bibliography. The expected investigation types are: Down-Hole test (DH), Cross-Hole test (CH), Seismic piezocone test (SCPTU), Seismic dilatometer test (SDMT), Multichannel analysis surface wave using active source (MASW), Ambient noise 1D or 2D seismic array (SA), Seismic refraction (SR), Seismic reflection (SRR), Seismic tomography (ST), Other investigations (OTHER); in addition to them, Compound Velocity (COMPOUND) indicates a combined velocity profile inferred by an expert user from all the available information (Fig. 9a). By clicking on magnifying glass icon at the page bottom (Velocity Profile subsection) it is possible to visualize values of velocity mean (V_{S30} or V_{Seq}), bedrock velocity mean, and the tabular form of the subsoil velocity profile described by depth (z defined from depth TOP to depth BOTTOM), V_S and V_P with corresponding standard deviation (Fig. 9b).

Non linear curve provides details on investigation type, distance from the site, survey date, compiler's notes, figures, monography, and specific bibliography. The expected investigation types are: Resonant Column test (RC), Cyclic Torsional Shear test (CTS), Double Specimen Direct Simple Shear test (DSDSS), Other investigations (OTHER). By clicking

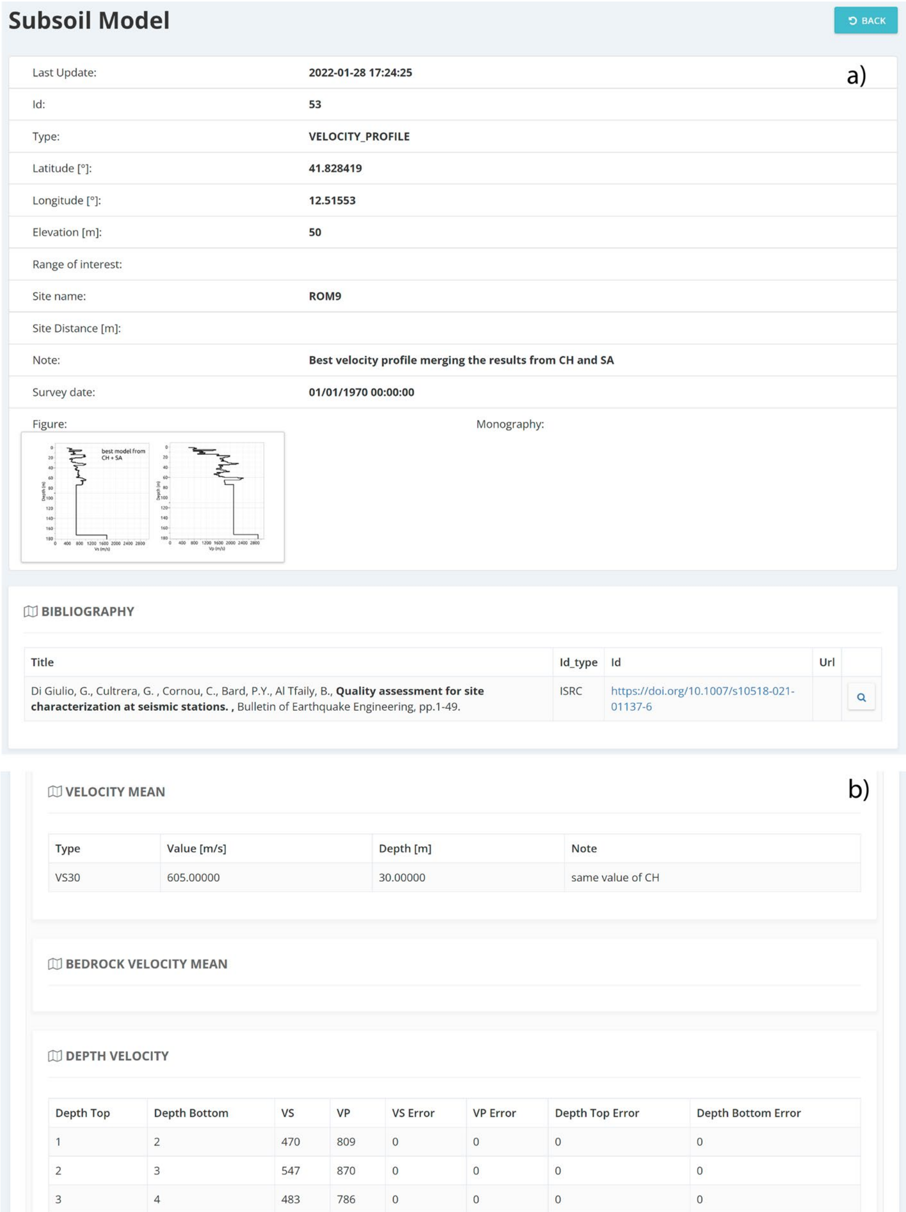


Fig. 9 Subsection details on Geophysics section for IV.ROM9 (Roma): **a** Subsoil model page for velocity profile compound and **b** corresponding velocity values displayed by clicking on magnifying glass icon at the page bottom

on magnifying glass icon at the page bottom (Non Linear Curve subsection) it is possible to obtain the tabular form of the shear strain, in terms of stiffness modulus (G), normalized stiffness modulus (G/G0, where G0 is the small strain modulus), damping ratio, and/or excess pore pressure ratio.

Other investigation contains details on geophysical and geotechnical parameters other than Velocity Profile and Nonlinear Curve, together with the survey distance from the site, date, notes, figures, and specific bibliography. The expected investigation type are: Borehole log (BH), Piezocone test (CPTU), Flat dilatometer test (DMT), Standard penetration test (SPT), Dynamic probing super heavy test (DPSH), Vane test (VT), Static laboratory test (SLAB), Ambient noise measurement (AN), Electrical tomography (ET), Time domain electromagnetic method (TDEM), Kappa analysis (high-frequency attenuation factor; KAPPA), Quality factor (Q), Other investigations useful for the subsoil model seismic characterization (OTHER).

3.6 Site classification

Site Classification section includes information on topography and soil classes according to a specific Seismic Building Code (Online Resource 2).

In the following we describe the thematic subsections.

Topography class stores the Topography class value and the type of morphological analysis to infer it (Cartography, DEM, GIS analysis, Specific studies, Other), the indication on the preferred one and the reference Seismic Building code.

Site class contains the site class values (also called "Ground Type" or "Soil Class") and the type of analysis to infer it (Array measurement, Borehole/Cross-hole/Down-hole, Geology, Geotechnical, MASW, Other), the indication on the preferred one and the reference Seismic Building code.

3.7 Queries

From the *Search* item of the *Sites* Menu bar it is possible to carry out simple queries of the database about site position, class, V_{S30}, V_{Seq}, frequency and amplitude peak, morphological classification, housing and polarization. The fields to search can be filled by expanding the corresponding button. The search returns the list and the map of stations that satisfy the required conditions. The list can be downloaded in csv format with name and site position.

4 Data and statistics

CRISP is a database that allows to gather data of different nature and collected in different contexts: it takes the maps and geological information through web services, technical information on seismic stations from local repositories, seismological and geophysical analysis from specific studies, geognostic surveys by specialized firms, and any other type of information defining the site response from the scientific literature. The nature of the CRISP archive leads the database to be constantly updated and expanded over time with new data produced or found within the scientific community, such as the ones related to new seismic stations, availability of up-to-date maps, further geophysical surveys and seismological analyses. These updates will not lead to the publication of a new archive release, but the *Last update* field in each record allows the user to identify the last entry or the modification date.

Table 1 Statistics of information stored in CRISP and referred to the main sections

Section	Records	Stations
Housing		
Data Quality	897[a]	299
Instrument Housing	many	223
Geology		
Stratigraphy	44[b]	23
Geological Review	358[c]	332
Morphological Classification	481[d]	341
Lithological Classification	341	341
Geological Classification	341	341
Cross section	26	26
Cartography	688[e]	341
Seismology		
HVeq	13	13
HVnoise	345[f]	334
Polarization	121	121
Geophysics		
Non linear curve	1	1
Velocity profile	36 [g]	29
Velocity mean (V_{S30}, V_{Seq})	45 [h]	29
Bedrock velocity	20	20
Site classification		
Topography class	many	341
Site class	395[i]	334

Records: total number of entered values, including multiple values in single sites. Stations: number of sites having at least one value of the respective indicator

[a]Seasonal or annual or both

[b]Exploration survey, pilot well, well-aqueduct, water well, and 2 geognostic surveys

[c]26 stations having both ISPRA and detailed reports

[d]Both DEM 10 m and 30 m

[e]Geological and lithological maps at 1:100.000

[f]6 HV continuous analysis and 9 HV both daily and continuous, 1 with 3 different analyses

[g]4 with both MASW and SA, 1 with 4 different profiles-ROM9

[h]36 V_{S30} and 9 V_{Seq}

[i]334 from geology, 27 sites with more than 1 estimate, that is from V_S profile and geology

The data collection presently included in CRISP is summarized in Table 1, where the sections that do not contain data are not explicitly indicated. In the following we present a brief description of the standardized procedures which provided homogeneous results to all stations.

4.1 Sites

At the time of database publication (January 2022), CRISP archive contained 342 sites where stations of the RSN Italian network have been installed: 37 of them are instrumented with an accelerometer only, 159 with a velocimeter only, 122 with both accelerometer and velocimeter, 23 abandoned locations (closed stations) at 31/03/2022. Two criteria were preliminarily identified for choosing the sites to be included in this first release of the database: stations operating on January 1st 2015 and with the possibility to download the seismic data from EIDA (http://eida.ingv.it/, last accessed 10-10-2022). Later on the list was integrated with other stations.

The instrumentation characteristics come from the INGV SeisNet database of RSN (Pintore et al. 2012; http://terremoti.ingv.it/en/instruments/station, last accessed 10-10-2022), whereas the coordinates of all selected stations were reviewed because the accurate site location is relevant for the seismic response evaluation. This is not the case of the earthquake location, for which tens of meters of position inaccuracy are often negligible: as a matter of fact, the International Seismological Centre (http://www.isc.ac.uk/registries/registration/, last accessed 10-10-2022) requires to change the station code only when the station shift is greater than 1 km. For each CRISP sites, the coordinates have been checked through a comparison between the GPS position provided by the station, the geodetic antenna of the RING network (http://ring.gm.ingv.it, last accessed 10-10-2022) near the station, when available, and a visual check on googleEarth.

4.2 Housing

Due to the large number of stations and the long installation-history of many of them, it was not always easy to find information and pictures to describe the Instrument housing. They have been gathered from local INGV archives and from photos and interviews to the network technicians or local collaborators.

Regarding Data quality, automatic procedures have been developed by INGV to facilitate the quality check of the seismic network, both in terms of continuity and completeness of the data themself. In particular, the SQLX package (https://www.codevintec.it/nanometrics-sqlx-it, last accessed 10-10-2022), installed at INGV in 2015 (Marzorati and Lauciani 2015), takes as input waveforms and metadata contained in the INGV seismic database (EIDA) and continuously produces a series of control diagrams such as Power Spectral Density (PSD, Peterson 1993) and Probability Density Function diagrams (PDF, McNamara and Buland 2004), compared with the reference curves of the Peterson (1993). In this way, it is possible to have a picture of how the noise level is distributed in amplitude and frequency, during the whole inspected time interval (weekly, monthly, yearly). The figures stored in CRISP were downloaded from the internal INGV website, and the results of the automatic analysis were taken from an internal Mysqlx database via dedicated web services (http://terremoti.ingv.it/webservices_and_software, last accessed 10-10-2022) and formatted to be archived in CRISP.

4.3 Geology

Many data archived in the Geology section (stratigraphy, geological review, lithological classification and geological classification) come from national geological service databases (ISPRA) and from detailed studies performed so far under DPC-INGV agreements.

Geological and lithological maps at the different scales (1:100.000 for all sites and 1:50.000 for about 40% of sites) are visualized through a Web Map Service (WMS) protocol that queries the ISPRA databases (https://www.isprambiente.gov.it/en/services/cartography/geological-and-geothematic-maps, last accessed 10-10-2022). This is why any dysfunction of the ISPRA web portal prevents the visualization on the CRISP front-end.

ISPRA also provides the geological and lithological classification at the site location through Geography Markup Language (GML file), which serves as a modeling language for geographic systems as well as an open interchange format for geographic transactions on the Internet. Moreover, they provided a report and a related conceptual model obtained through a joint analysis of the data relating to geognostic surveys available at 2016 in the ISPRA and regional databases, and in the Seismic Microzonation web portal (https://webms.it, last accessed 10-10-2022). Additional reports are realized for several permanent strong motion stations within DPC-INGV agreements, with the use of dedicated geological and geophysical surveys.

The morphological classification derives from morphometric analyses of high resolution Digital Elevation Models (DEM), performed with the semi-automatic procedure of Pessina and Fiorini (2014) that releases maps showing station location, slope classes and morphological ridges. They have been obtained by using two DEMs with different resolutions (10 m and 30 m). The two morphological classification types (Basin and Relief) are obtained by photo interpretation of aerial and satellite images also found in GoogleEarth.

4.4 Seismology

The analyses on noise (for HVNoise and signal polarization) and low magnitude earthquake (for HVEQ) have been performed on velocimetric recordings downloaded from the European Integrated Data Archive portal (EIDA; http://eida.ingv.it, last accessed 10-10-2022); temporary velocimetric recordings have been used for stations equipped with accelerometer sensor only.

Regarding HVNoise, a standard analysis based on Geopsy software (www.geopsy.org, last accessed 10-10-2022; Wathelet et al. 2020) was performed for all sites on 12 daily tracks (one per month) to evaluate seasonal, daily and random variation. Analysis results are given in terms of HV ratios obtained by (i) the geometric mean of the two horizontal components and (ii) the rotated horizontal components at steps of 10° from 0° to 180°. On these latter HV ratios, a criterion proposed by Pischiutta et al. (2018) is exploited to discriminate peaks associated with directional ground motion.

Moreover, for some sites the continuous HV analysis on noise (HVNoise) and earthquakes (HVEQ) is executed over a period of several years with the procedure proposed by Vassallo et al (2022). Currently no SSREQ has been calculated for any station.

The signal polarization has been computed with the time–frequency technique (Vidale 1986; Burjànek et al. 2010) if directional amplifications are found in HVNoise.

4.5 Geophysics

This section contains subsoil models and cross sections derived from geological and geophysical investigations performed within national projects which were focused on the seismic characterization of the main national seismic networks. The geophysical surveys are mostly based on 1D-2D surface-wave array analysis on ambient vibrations or active data usually generated by a sledge-hammer (Foti et al. 2011; Felicetta et al. 2017). The velocity profile computation is derived from inversion of dispersion curves or by the use of borehole data, if any; the geophysical and geological surveys, from field operation to data analysis, are collected in individual reports.

4.6 Site classification

Currently CRISP archives the site class inferred from geology and from V_S profiles. The geology-based class uses a method proposed for the national territory (Di Capua et al. 2016), which defines the lithoseismic subsoil classes by combining the surface lithological units present in the lithological map of Italy at a scale of 1:100.000, according to the European seismic code (EC8, 2004). Specific procedures have been developed to query the data provided by the aforementioned work and return the value of the site class corresponding to the geographical position of the stations. Moreover, for a subset of sites the classes are derived from different direct measurements (V_S profile from array, downhole or crosshole measurements) and according to national (NTC08, 2009; NTC18, 2018) and international (EC8, 2004) building codes.

The topographical class has been assessed according to the EC8 prescription, using the methodology based on morphometric analysis applied to high resolution digital terrain models with the support of a Geographic Information System (Mascandola et al. 2021).

For both site and topography classes, the preferred value has been identified with expert judgment.

5 Final considerations

CRISP represents a suitable web portal that collects all information on seismic sites belonging to the Italian National Seismic Network RSN.

The database was designed to include many different fields and heterogeneous data: geographic, geological, seismological and geophysical information are stored and distributed as photos, figures, maps, pdf reports, tables, numerical and graphical models. The content implementation requires continuous updates with new information and data from specific analysis and detailed studies always referenced through the bibliography field.

At the same time, the database is easily extensible with new fields increasing the potential for use. Although we made an effort to include all the possible fields related to site effect estimation, the availability of new funds will be fundamental to implement the necessary improvements that may arise in the future and to carry out new analysis including additional useful parameters. Further database development will be the increase of the number of characterized RSN stations, the addition of the quality index field dedicated to the evaluation of the seismic characterization completeness (Giulio et al. 2021), the publication of APIs for allowing the users to extract the collected information. Through the use of the web services, CRISP can become an unified source of homogeneous and reliable data providing site information to the Italian archives linked to the seismic network.

The proposed database fits into the European efforts towards the complete site characterization of the seismic networks and the interoperability of the stored information through web services, as discussed by Cornou and Bard (2019) and others (see Cauzzi et al. 2021; Haslinger et al. 2022). This goal is necessary for qualifying the records metadata as the contents of the database can be used to carry out many innovative studies in different fields, from seismic research and surveillance to engineering seismology and infrastructure, such as:

- for seismic surveillance, to individuate site amplification that may influence magnitude calculation and improve products in near-real time following an earthquake (e.g. Shake Map);
- for fundamental research, to include local amplification in the study of seismic source and wave propagation;
- for engineering seismology, to calibrate the ground motion prediction equations and improve the site-specific seismic hazard evaluation;
- for building regulations, to define criteria for the attribution of the soil class and provide corrective factors to apply in antiseismic normative and seismic microzonation;
- for research infrastructures, to improve the quality of the recording metadata for a correct use of the seismological data as mentioned in the EPOS infrastructure objectives, to check and understand any signal anomalies.

For these reasons the CRISP database can be an inspiration model and a starting point for other national institutions to set up the characterization of the permanent seismic station sites. Furthermore, it can be a motivation for network operators to perform site response studies at the station locations also before the sensor installation.

We look forward to having feedback from the users to improve the website and to receive contributions on available information to be included in the database.

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Data availability The datasets generated and/or analyzed during the current study are available in the CRISP website http://crisp.ingv.it (https://doi.org/10.13127/crisp), last accessed 10-10-2022. Several lithological and geological maps around the stations and information on the local geology are acquired through webservices from ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale, https://www.isprambiente.gov.it/, last accessed 10-10-2022), under the INGV-ISPRA 2016–17 Agreement (protocol INGV 2016/0003777 of 04/04/2016): "Scientific and technical collaboration aimed at the geolithological characterization of the sites of the stations of the national INGV seismic network "(Scientific Coordinators: P. Bordoni and G.M. Monti). Seismic data for seismological analyses have been performed on velocimetric recordings of Rete Sismica Nazionale (RSN; https://doi.org/10.13127/SD/X0FXNH7QFY) and available in the European Integrated Data Archive portal (EIDA; http://eida.ingv.it, last accessed 10-10-2022).

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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