Regional scale shear wave velocity profiles for ground response analyses uncertainties evaluations – the Piedmont Region (NW Italy) Database.

Cesare Comina [1], Guido Maria Adinolfi [1*], Carlo Bertok [1], Andrea Bertea [2], Vittorio Giraud[2], Pierluigi
Pieruccini[1]

[1] Dipartimento di Scienze della Terra, Università degli studi di Torino, Torino, Italy.
[2] Seismic Sector, Piedmont Region, Pinerolo, Italy.

Correspondence to: Guido Maria Adinolfi (guidomaria.adinolfi@unito.it)

Abstract. The prediction of earthquake ground motions, and consequent seismic hazard of a specific area of study, is usually based on ground response evaluations of a statistical representative sample of possible soil and rock profiles. With this aim shear wave velocity (Vs) properties of the profiles are of paramount importance, given that uncertainty in this parameter play a major role in ground motion prediction and in its variability. Usually, stochastic procedures are adopted to model this uncertainty, and several stochastic approaches have been developed. These approaches should be however calibrated on detailed geological-geomorphological information and specific Vs profiles databases. Within this context the present paper is aimed to provide a new extensive database of Vs profiles over the Piedmont Region (NW Italy). These data are obtained through a specific workflow developed for their evaluation at the regional scale merging the information of specific geological-geomorphological modelling and devoted geophysical data collection. The obtained database (https://doi.org/10.5281/zenodo.13685087) could be used as the basis of Vs randomization approaches also in different geological contexts and results from the specific data analyses performed could be adopted as reference for similar materials in analogous geological contexts.

1 Introduction

The prediction of earthquake ground motions, and consequent seismic hazard of a specific area of study, is usually based on ground response evaluations of a statistical representative sample of possible soil and rock profiles (i.e. seismo-stratigraphical profiles) in the area (Pieruccini et al., 2022). As an example, "amplification abacuses" are widely diffused simplified tools for the quantification of local stratigraphic amplifications of the seismic ground motion over large areas, i.e. Regions. These evaluations are therefore the result of a compromise between generalization and specialization (Peruzzi et al., 2016) and several approaches have been adopted in the past for their formulation (e.g. Pagani et al., 2006). One of the challenging aspects of these kind of analyses is the definition of a Geological-Geomorphological Model (GGM) at regional-scale build on purpose

for the assessment of shear wave velocity (Vs) properties of the seismo-stratigraphical profiles, their spatial distribution and related geological variability. Particularly, for regional-scale studies the uncertainty in the Vs profiles definition is considered as the main source of uncertainty in ground response evaluations (Toro, 2022) and must be therefore taken into account with devoted attention.

35 Usually, stochastic procedures are adopted to model this uncertainty. Several stochastic approaches have been developed through the years with parameters that should be however calibrated on specific GGMs and Vs profiles databases (e.g. Toro, 2005; Shi and Asimaki, 2018; Passeri et al., 2020). Indeed, older and widely used formulations of these approaches, e.g. Toro (1995), provided parameters calibrated on California profile data to be used elsewhere. New generic and site-specific stochastic Vs models should be therefore developed using specific databases or increased databases number and population, together

40 with insights gained in the practical use of these models.

Several research efforts have focused on constructing and analysing Vs databases for different purposes, including: 1) developing site investigation guidelines, as demonstrated by EPRI (1993), with a database containing over 350 Vs profiles (mainly within United States); 2) managing uncertainties, as in Toro (1995), who compiled a database containing 745 Vs

45 profiles from the PEA (Pacific Earthquake Analysis) database for the development of a geostatistical model; 3) addressing data gaps, as shown by Stewart et al. (2014), who created a Vs database for Greece using open-source data to extrapolate Vs,z (the harmonic average shear-wave velocity profile down to depth z); 4) creating empirical correlations, as in Passeri et al. (2021), who developed a database of 71 Vs profiles for statistical analysis and model calibration; 5) validating simplified methods, as in Aimar et al. (2019), who used a Vs database to validate soil amplification factors in the Italian building code

50 NTC (2018); 6) assessing measurement uncertainty, as in Moss (2008) and Comina et al. (2011), with smaller databases of 30 and 10 Vs profiles, respectively; and 7) supporting ground motion studies, as in Wang et al. (2019), who established the United States Community Vs database for ground motion and site response analysis.

In the present paper a new methodological workflow for the assessment of a GGM and related Vs profiles distribution at regional scale is presented, which is used to develop a new geological and geophysical database. Using existing datasets,

55 implemented and validated on purpose, a new geographic database for ground response at regional scale was developed. The methodological workflow is tested over Piedmont Region in North-West Italy. This Region includes: the Alpine Mountain environment; the Foreland Hilly landscape both with different bedrock and cover terrains typologies and thicknesses; the Po River plain, and secondary alluvial plains, with thick Quaternary deposits overlying at depth different bedrocks. Following the proposed workflow, we assessed a new Vs database performing a quality control of all the available datasets and producing

60 additional information in areas not covered or poorly covered by data.

Therefore, this paper has three main aims: i) provide a new, extensive (i.e. containing more than 1000 profiles), database of Vs profiles to be used as the basis of randomization approaches also in different geological contexts; i) provide median properties of the different investigated geological-geomorphological domains to be adopted as reference for similar materials

in analogous geological contexts; iii) provide a workflow to be adopted for the evaluation of Vs profiles distribution at the

65 regional scale by merging geological-geomorphological information and specific geophysical data collection.

2 Geological-geomorphological model

The assessment of a Geological-Geomorphological Model (GGM) at regional scale is the first step of the proposed procedure. In order to get an updated synthesis of the geological knowledge the Geological Map of Piedmont Region (1:250000 scale) (Piana et al., 2017a,b, 2020) has been used. This map is available as open source Geodatabase (Geoportale-ARPA) and

70 therefore can be used for on purpose reclassification.

Three main reclassification levels of the geological information are needed to obtain a GGM consistent with the seismic perspective:

1) Reclassification of the outcropping and subsoil units as Geological Bedrock and Cover Terrains. To simplify the model, Cover Terrains are usually those of Quaternary age, whereas Geological Bedrock can be considered as pre-

75 Quaternary (Pieruccini et al., 2022);

2) Classification of each Geological Bedrock and Cover Terrain according to their main geotechnical properties (Romagnoli et al., 2022; Gaudiosi et al., 2023);

3) Gathering of the original formations units into different Geological-Geomorphological Domains (GGDs) based on their stratigraphic-sedimentological characteristics and the geomorphological context of outcrop, including the range

80 of thicknesses of expected subsoil characteristics.

The Geological and Geomorphological setting of the Region is the result of a complex geodynamical evolution that since the Mesozoic led to the formation of two passive continental margins and two oceanic zones. The collision of the two margins after the Eocene is the beginning of the Alpine-Apennines orogenesis, characterised by complex metamorphic, magmatic and sedimentary processes (Piana et al., 2017b and references therein). The definitive emersion of the area is marked by the Middle

85 Pliocene-Quaternary continental successions and the present-day landscape, the consequence of this complex evolution, can be subdivided into four main Landscape Systems, or physiographic units.

1) Mountain Ridges

    a. Alpine Ridge, extending form SW to the NNE with an arcuate shape

    b. Apennine Ridge, E-W trending in the south-eastern part of the Region

90 2) Hills of Torino, Langhe and Monferrato

3) The Quaternary alluvial basins and valley systems of the River Po

    a. The Po plain fed by rivers of alpine provenance

    b. The floodplains of the valleys crossing the Alpine Ridge

    c. The floodplains fed by the rivers crossing the Apennine Ridge

95 d. The floodplains fed by the rivers crossing the Hills

4) The Quaternary frontal moraines and related systems of fluvio-glacial and fluvio-lacustrine sediments of the main glacial amphitheatres extending in the Po plain at the mouth of the main alpine valleys (es. Ivrea, Rivoli).

The analysis and reclassification of the available geological and geomorphological database allowed the identification of 13 different Geological-Geomorphological Domains (GGD) (Figure 1).

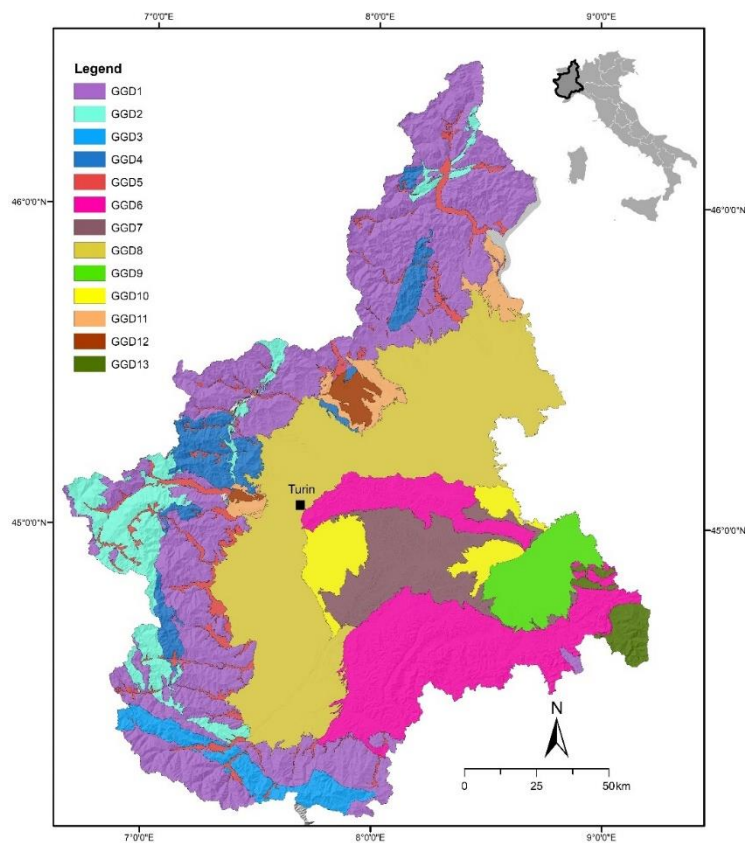



Figure 1. Map of the Geological-Geomorphological Domains within the Piedmont Region.

Each GGD is characterized by homogeneous Geological Bedrock typologies and potentially different litho-stratigraphic settings including Cover Terrains. The GGDs are related to (Table 1): a) the Alpine mountain chain with different bedrocks (GGD 1 to 4) including the main Alpine valleys (GGD 5); b) the foreland hilly landscape both with different bedrock and cover terrains typologies and thicknesses (GGD 6 and 7); c) the Po river plain, fed by Alpine rivers, with thick mostly coarse-grained Quaternary deposits overlying at depth different bedrocks (GGD 8); d) minor alluvial plains fed by rivers coming from the Apennines and the foreland hills with thick mostly fine-grained Quaternary deposits overlying at depth different bedrocks (GGD 9 and 10); e) the moraine amphitheatres and the associated fluvio-glacial and lacustrine deposits (GGD 11 and 12); f) the complex successions belonging to the Ligurian Units (GGD 13).

115

Table 1. The main characteristics of the GGDs

Physiographic Units	GGD		GEOLOGICAL BEDROCK	COVER TERRAINS
ALPINE RIDGE	1	METAMORPHIC AND MAGMATIC ALPS	lapideous rocks and alternating litotypes	slope, alluvial, alluvial fan, glacial, fluvio glacial, mainly gravelly, packed, up to 100 m thick
	2	OCEANIC SERPENTINITES	lapideous to foliated rocks	
	3	OCEANIC CALCESHISTS	alternating lithotypes often weathered	
	4	CARBONATIC ALPS	lapideous rocks and alternating litotypes	
	5	ALPINE RIVER VALLEYS		mainly unsorted alluvial gravels, pebbles and boulders, packed to cemented, up to 200 m thick
FORELAND HILLS	6	OLIGO-MIOCENE BASINS	alternating lithotypes, granular and cohesive	slope and alluvial unsorted gravels and sands up to 50 m thick
	7	PLIOCENE BASINS	mainly cohesive	slope and alluvial sands and silts up to 50 m thick
QUATERNARY ALLUVIAL BASINS	8	PO RIVER PLAIN		alternances of dominant gravels, sands and silts, from loose to packed, up to 100 m thick
	9	APENNINES RIVERS PLAIN		alluvial mainly gravels alternated to sands and silts loose to packed, up to 80 m thick
	10	HILLS RIVERS PLAIN		alluvial mainly sands and silts, loose to packed, up to 80 m thick
GLACIAL AMPHITHEATRES	11	MORAINE AMPHITHEATRE		mainly silts and clays loose or weakly packed, up to 40 m thick
	12	FLUVIOGLACIAL AND LACUSTRINES		unsorted gravels, pebbles and boulders with sandy-silty matrix, loose to strongly packed, up to 200 m thick.
APENNINE RIDGE	13	LIGURIAN UNITS	alternating lithotypes often weathered	slope and alluvial unsorted gravels up to 50 m thick

3 Data collection and QC

Once the GGDs were identified the available geotechnical and geophysical databases from Regional Authority's repositories
120   were used for the geological/geotechnical characterization and for their Vs parameterization. The main source of information
was the Geotechnical Database of ARPA (Regional Agency for Environmental Protection of Piemonte Region) Piedmont
(Geoportale-ARPA). This database contains several stratigraphic logs with various depths and quality. Attention was focused
on the subset of about 3000 stratigraphic logs reaching at least 30 m in depth. Of these, more than 1000 logs, judged to be of
higher quality, were consulted and are included in the presented database (Figure 2). Most of these logs reached the geological
125   bedrock and in these cases the bedrock depth was reported as information. Also, the prevalent properties of the Cover Terrains
within the first 30 m depth were classified, when possible, according to the main textural and characteristics. The final data
format used in the database for this information is reported in Table 2.

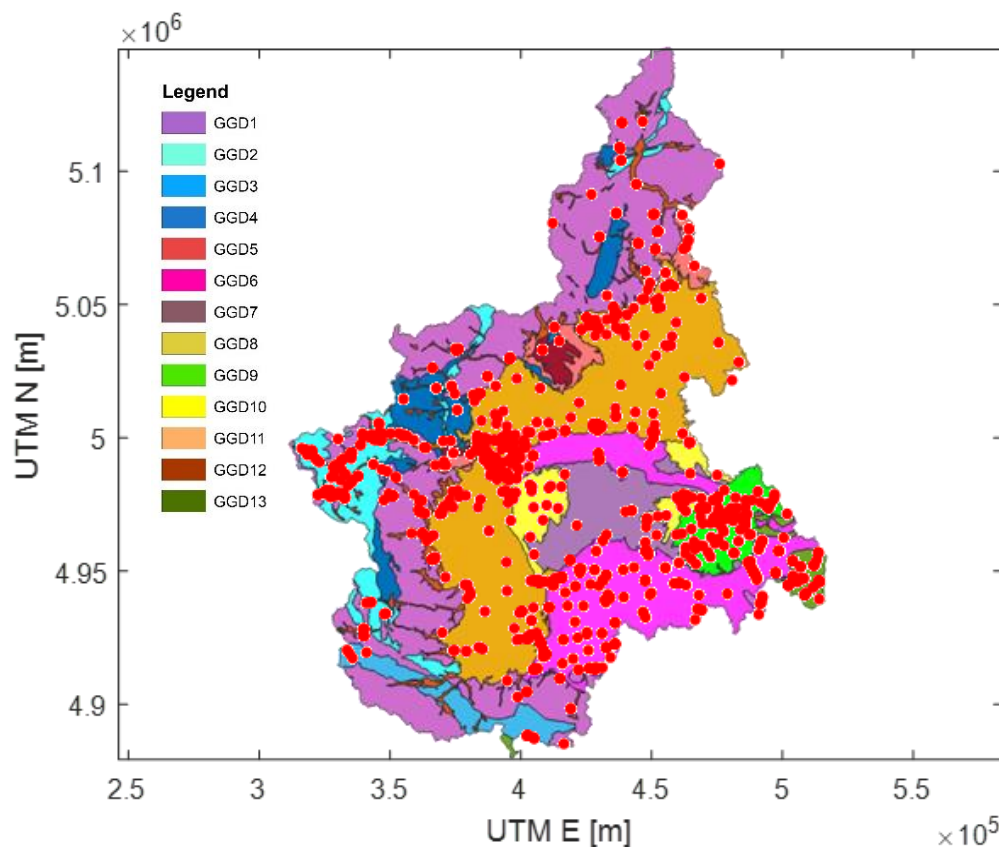



Figure 2. Map of the GGDs' and the distribution of the stratigraphic logs (red dots) analysed (from Geoportale ARPA).

130

135

Table 2. Data format for the geotechnical information contained in the database. Data values for the bedrock depth and texture attributes derived by the available logs. UTM E and UTM N are the kilometric coordinate system used for
140 **their georeferentiation (WGS84 UTM32N)**

	UTM E [m]	UTM N [m]	Geologic Bedrock depth [m]	Texture
value	-	-	Bedrock not reached or not clearly identified = 999	C clay G gravel S sand R rock X not available

With respect to the shear wave velocity properties the main source of data was the same Geoportale ARPA. The analysis of this database allowed the assessment of about 2000 Vs profiles coming from both invasive and non-invasive tests. To fill the gap in the geographic data distribution we added more Vs profiles thanks to the collaboration with Techgea S.r.l., a leading

145 geophysical private company that provided about 300 Vs profiles and by performing specific field tests or implementing specific information from literature data (about 50 Vs profiles).

Geophysical data underwent specific Quality Control (QC) in order to consider only reliable and state of the art information. Particularly, the data deriving from Multichannel Analysis of Surface Waves (MASW) tests (the most widely diffused technique for Vs profile determination) underwent a specific QC consisting in checking: 1) consistency of the dispersion curve,

150 that should present a clearly visible and continuous fundamental mode in the frequency band of interest; 2) when multiple dispersion modes occur, they should be well separable, well distinguishable and reliably interpretable independently; 3) a picking of the dispersion curve reliable and fitting with the spectral maxima of the seismogram transform used for the analysis; 4) inversion of the data leading to a synthetic dispersion curve having a good correspondence with the experimental data; 5) depth of the Vs profile compatible with the minimum frequencies observed in the analysis, i.e. investigation depth less than at

155 least the maximum wavelength (preferably half the maximum wavelength); 6) Vs profile matching the minimum parametrization criterion, i.e. number of analysed layers compatible with the experimental information. The QC allowed the identification of about 1000 high-quality Vs profiles distributed over all the GGDs that were included in the final database (Figure 3). The final data format used in the database for the Vs profiles information is reported in Table 3.

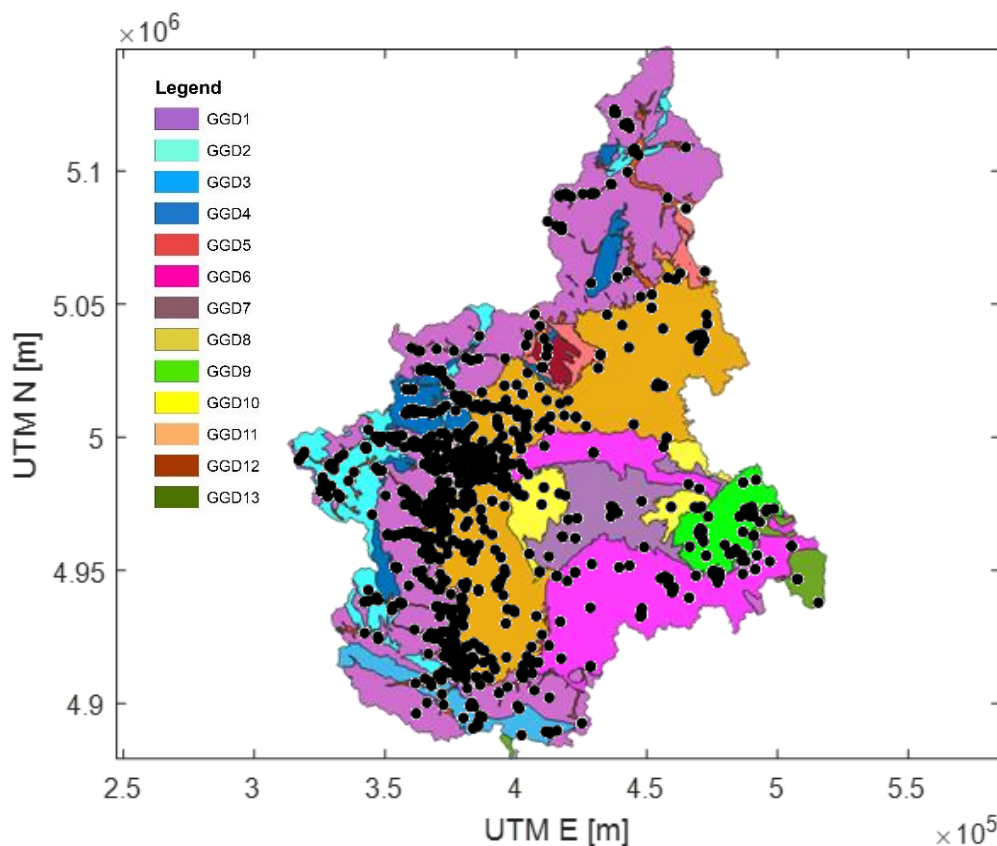



Figure 3. Map of the GGDs' and the distribution of the Vs profiles (black dots) analysed (from Geoportale ARPA) after QC.

Table 3. Data format for the geophysical information contained in the database. Data values for the attributes of depth of seismic layers and Vs values. UTM E and UTM N are the kilometric coordinate system used for their georeferentiation (WGS84 UTM32N)

	UTM E [m]	UTM N [m]	Depth [m]	Vs [m/s]
value	-	-	Intended to be the layer interface depth	Intended to be the shear wave velocity above the layer depth

Both geotechnical and geophysical data distribution is influenced by the aims for which the different field tests were conducted. Particularly for geophysical data most information is inherited by the Seismic Microzonation studies, performed mainly on the Municipalities and settlements located within the Alpine valleys and at the border between the Alpine chain and the Po plain in the western sector of the Region, that is the area with higher Seismic Hazard. Data results therefore more concentrated

within and around the main urban settlements and most populated areas, that are the main targets for such type of studies (Figure 3).

Nevertheless, the obtained data allow to perform relevant analysis of the properties of the different materials characterizing each GGD. Particularly the final step of the workflow is the evaluation of specific Vs profile distribution within each GGD

175 and their comparison among different GGDs. Also, plots of data properties distributions at the regional scale were produced in order to evaluate their variability at the regional scale.

4 Results and Discussion

Presented below are the statistical analyses that characterize the database introduced in this work. These analyses provide detailed insights into the structure and distribution of the data, offering a comprehensive understanding of the regional Vs

180 profile distribution and its relevance to geophysical modelling. Also, suggested applications of the data made available within the paper are briefly discussed in the view of a wider use of the database within the interested community. The synthesis of the analysed parameters with respect to the Vs distribution for the different GGDs is reported in Table 4. Data distribution is not uniform among the GGDs due to the inhomogeneous geographical distribution of the data. The most populated GGDs are respectively GGD 8 (Po River plain) and GGD 5 (Alpine river valleys) whose results of the performed analysis are shown in

185 Figures 4 and 5.

Table 4. Analysed parameters with respect to the Vs distribution for the different GDs.

GGD	Number of Vs Profiles	Average Vs,h [m/s]	Vs profiles reaching the seismic bedrock	eismic bedrock depth range [m]	Average bedrock Vs [m/s]
1	68	390	45	0 - 40	1020
2	34	405	21	4.5 – 40	1020
3	11	470	8	4 – 25	1250
4	20	450	15	0 – 18	1045
5	324	395	109	3 - 83	1050
6	62	390	26	0 – 83	990
7	16	300	1	-	-
8	362	380	66	2 – 46.5	975
9	41	405	12	7 – 34	1020
10	17	305	2	-	-

11	23	420	9	3 - 40	970
12	18	320	1	-	-
13	5	335	4	4 - 28	1195

The higher population density of Vs profiles is within the GGD8 (Po River plain), particularly next the city of Torino, and along the Alpine River floors (GGD 5) where most of the settlements are located. In these GGDs 66 Vs profiles for GGD 8 and 109 for GGD 5 reached the seismic bedrock, considered as Vs higher than 800 m/s (Figures 4b and 5b). It worth's mention that in GGD 8 the distribution of profiles reaching the seismic bedrock is concentrated near the borders with the Alpine chain (Figure 4a).

The Vs,z distribution of the non-bedrock layers was also computed for each profile (Figures 4c and 5c) together with the resulting Vs,h according to NTC (Figures 4d and 5d). The Vs,z is indeed usually considered as a closer representation of the physics of the earthquake amplification along the soil profile than the Vs layered profile (Comina et al., 2022). This allowed also to obtain a representative median Vs,z profile for the different GGDs (together with its standard deviation). The two GGDs show relatively similar distributions of both Vs,z and Vs,h reflecting the similarities of the Cover Terrains within these domains (see also later for more comments on this aspect).

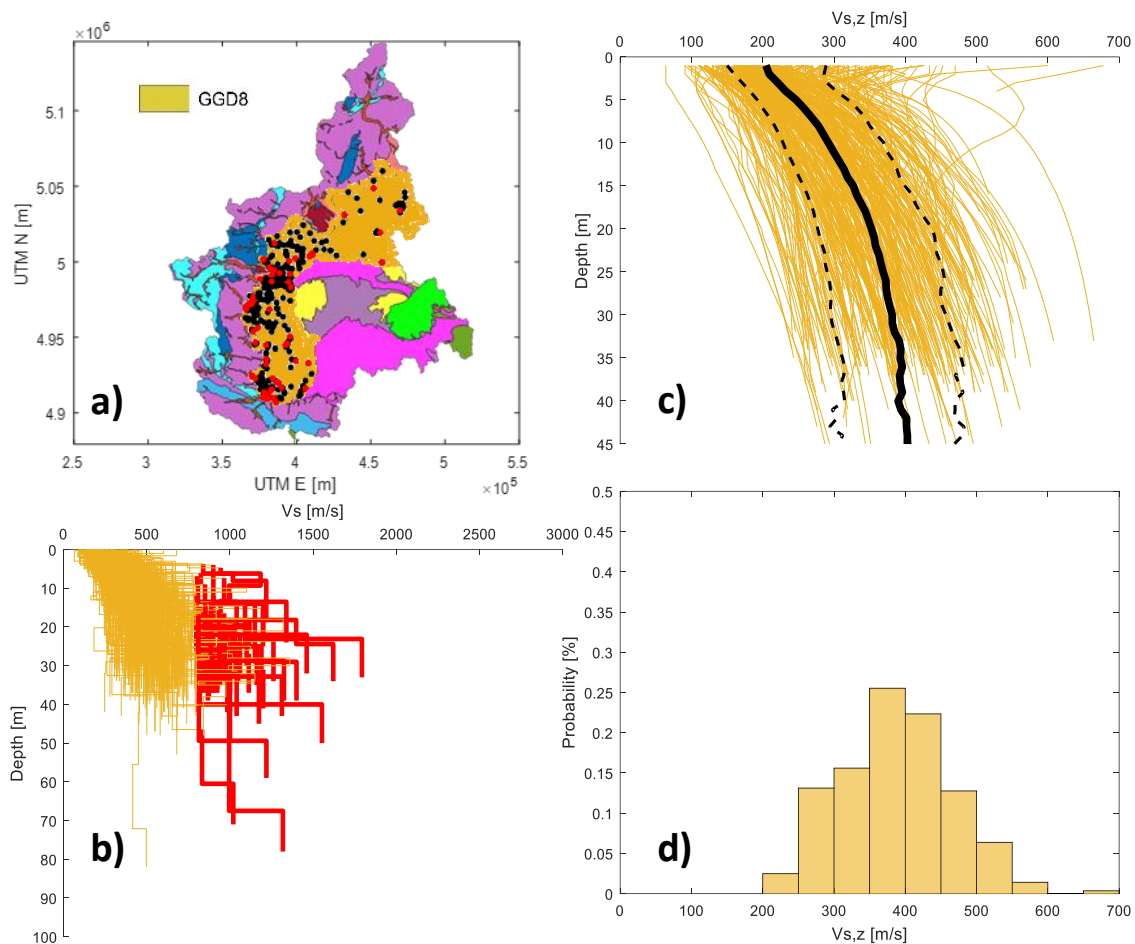



Figure 4. The results of the analysis for GGD 8: a) Vs profiles geographical distribution (black dots) and Vs profiles reaching the seismic bedrock (red dots); b) All Vs profiles (orange lines) indicating bedrock velocities (red lines); c) Vs,z profiles for the Cover Terrains or weathered Geological Bedrock and their mean (continuous black line) and standard deviation (dashed black lines); d) Vs,h distribution following NTC.

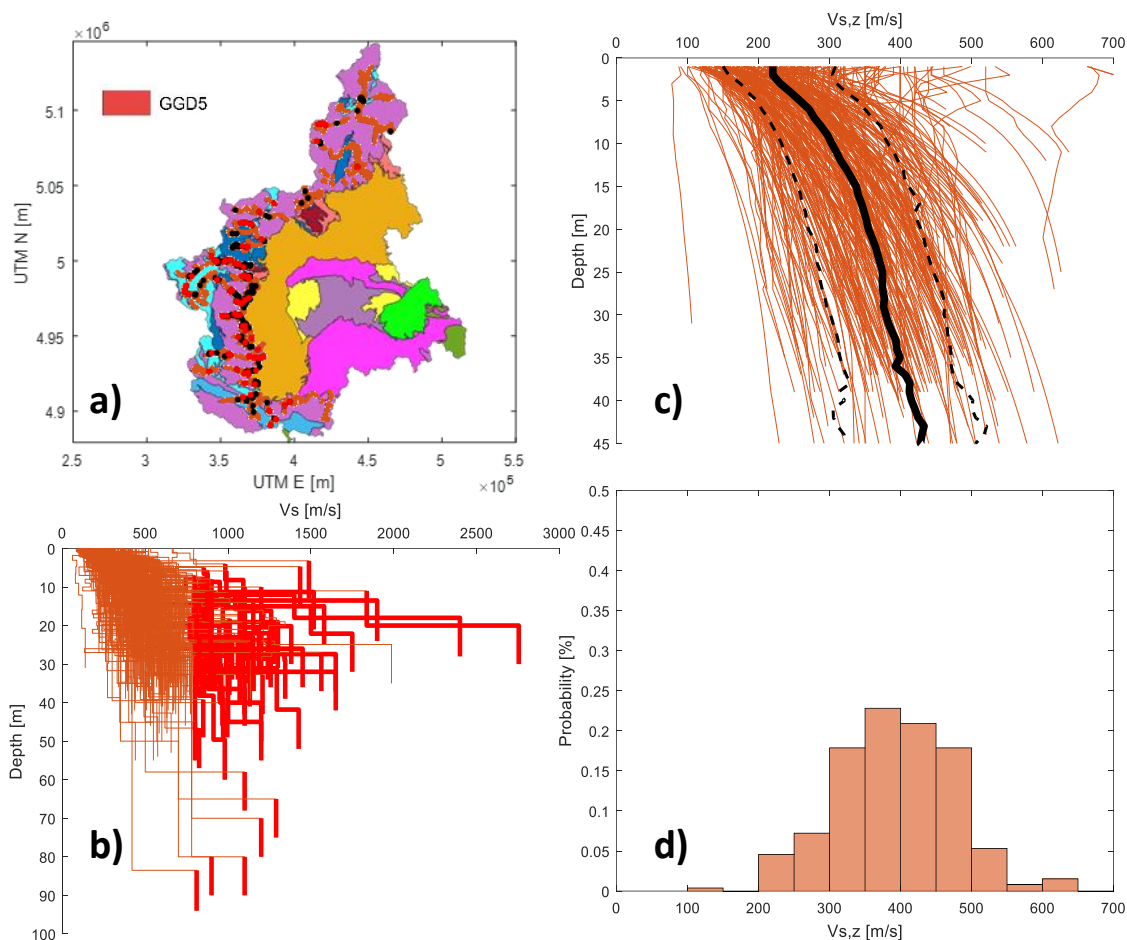
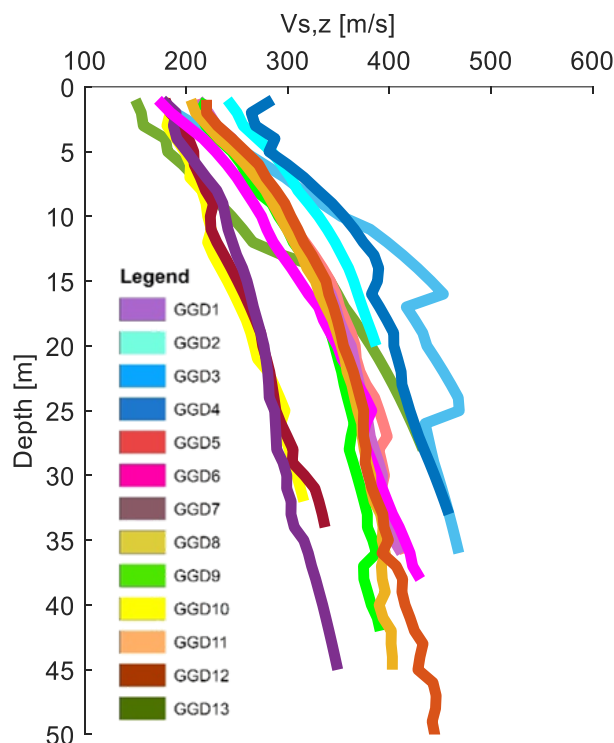



Figure 5. The results of the analysis for GGD 5: a) Vs profile distribution (black dots) and Vs profiles reaching the seismic bedrock (red dots); b) All Vs profiles (orange lines) indicating bedrock velocities (red lines); c) Vs,z profiles for Cover Terrains or weathered Geological Bedrock and their median (continuous black line) and standard deviation (dashed black lines); d) Vs,h distribution following NTC.

Similar procedure was applied for the other domains, keeping in mind the representativeness of the results as a function of data coverage and distribution. Particularly median Vs,z profiles were analysed in the different GGDs (Figure 6). The distribution of the median Vs,z profiles show groups of GGDs with very similar behaviours, reflecting similar properties of the Cover Terrains . Different GGDs' within the Alpine chain (GGDs 2 to 4) show higher Vs,z distributions with depth different to the others, due to the presence of very coarse-grained Cover Terrains, typically along the slopes (debris-slope, glacial, fluvio-glacial) or within the valley floors (alluvial, alluvial fan, glacial, fluvio-glacial), whose thickness is in the 3-100 m range. Conversely, GGD 7 (Hilly Pliocene Basins), 10 (Oligo-Miocene foreland hills) and 12 (Fluvio lacustrine) showed lower Vs,z distributions with depth, reflecting the mainly fine-grained (sands, silts, clays and minor gravels) slope, alluvial and lacustrine deposits, up to 50 m thick.

220 **Figure 6. Median Vs,z profiles for the Cover Terrains for each GGD.**

Following a global approach to the data analysis the median Vs,z profiles, eventually merged between similar GGDs, could be adopted as the basis for randomization and amplification simulation within the Region or in similar geological contexts. For this purpose specific randomization approaches, based on the same Vs,z (Passeri et al., 2020) or on usually adopted randomization criteria (e.g. Toro, 2022) could be adopted using the data contained in the database as fundamental starting

225 point. This proposed global approach allows to overcome the limitations inherited by the uncertainties of the specific litho-stratigraphic settings within each GGD, due to the regional scale of observations.

Moreover, the collected data for the database in this work allowed to produce Maps of relevant seismic parameters at the regional scale. Maps deriving from geological/geotechnical and geophysical information contained in the database have been produced in Surfer (Golden Software, LLC) environment considering a uniform interpolation grid of about 2 km for all the

230 data.

The Map of the prevalent geological-technical properties of the Cover Terrains within the first 30 m (Figure 7) shows the distribution based on the stratigraphical logs. The distribution of the Cover Terrains properties matches the geological-geomorphological information adopted for the GGDs definition. Prevalent coarse-grained Cover Terrains (gravels, pebbles to boulders) are distributed along the Alpine domains (GGDs 1 to 4), within the Alpine valley floors (GGD 5) and within the

235 Alpine and Apennine Alluvial plains (GGDs 8 and 9). Finer-grained Cover Terrains (i.e. sands, silts and clays) characterise

the Oligo-Miocene and Pliocene Basins (GGDs 6 and 7) and Hills rivers plain (GGD 10). A comparison with respect to the distribution of subsoil properties for GGD 8 and GD 6, clearly reflecting what commented above, is reported in Figure 8.

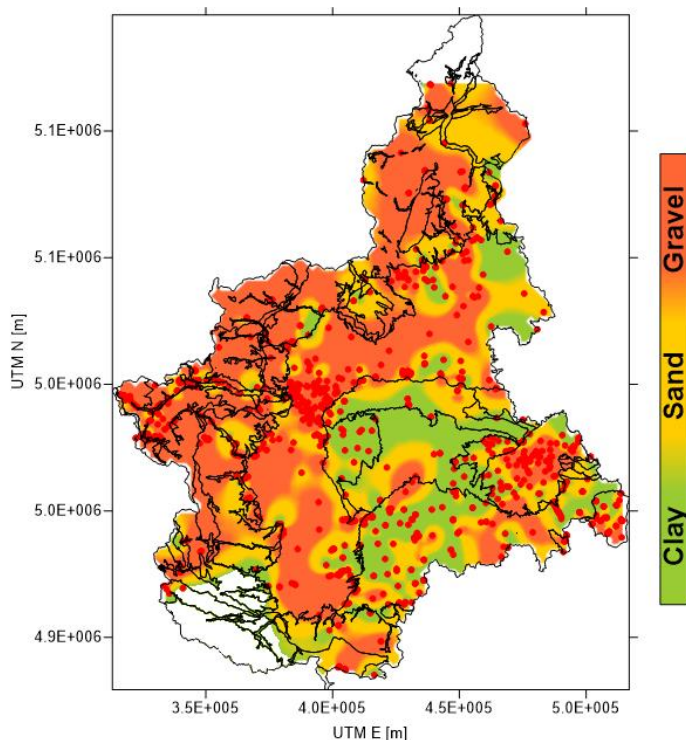



Figure 7. Geological/geotechnical information derived by the stratigraphical logs database: map of the prevalent
240 **properties of the Cover Terrains within the first 30 m.**

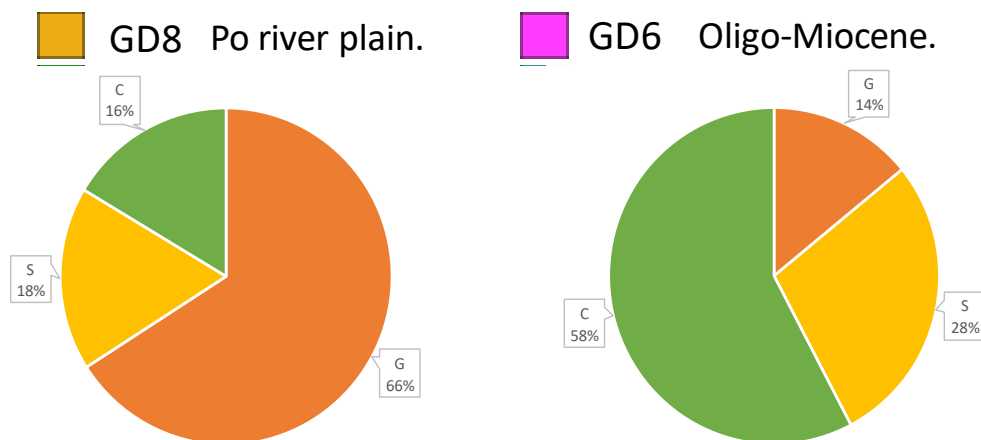



Figure 8. Comparison on the distribution of Cover Terrains properties within the first 30 m for GGD 8, on the left, and GGD 6, on the right.

245   For ground response evaluations this type of information is essential for the analysis of the subsoil nonlinear hysteretic behaviour. This is indeed usually described through appropriate shear modulus reduction and damping ratio curves. In common practice, in absence of specific laboratory tests, these curves can be estimated by employing empirical regression models (e.g. Vucetic and Dobry, 1991; Darendeli, 2001; Ciancimino et al. 2020; Wang and Stokoe, 2022), calibrated on large experimental datasets (e.g. Gaudiosi et al., 2023; Ciancimino et al., 2023), to correlate the soil physical properties, and their statistical

250   distribution in the investigated units, with their nonlinear hysteretic behaviour. With this respect the information contained in the databased presented in this work can be adopted as key data for large-scale regional hazard assessments or in similar geological contexts.

    A further essential complementary information for ground response analyses is the evaluation of the thickness of the Cover Terrains, i.e. the Bedrock depth. With this respect, using the data from the database, the estimated Geological Bedrock depth

255   distribution from stratigraphic logs (Figure 9) and the Seismic Bedrock depth distribution based on Vs profiles (Figure 10) have been compared.

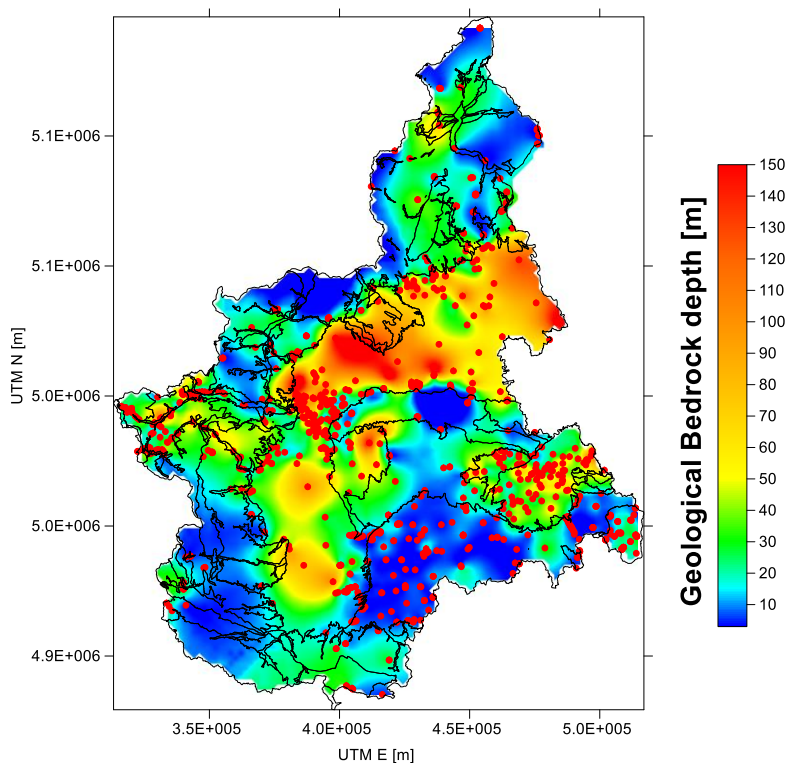



Figure 9. Geological/geotechnical information presented in the database: map of the estimated Geological Bedrock
260   **depths.**

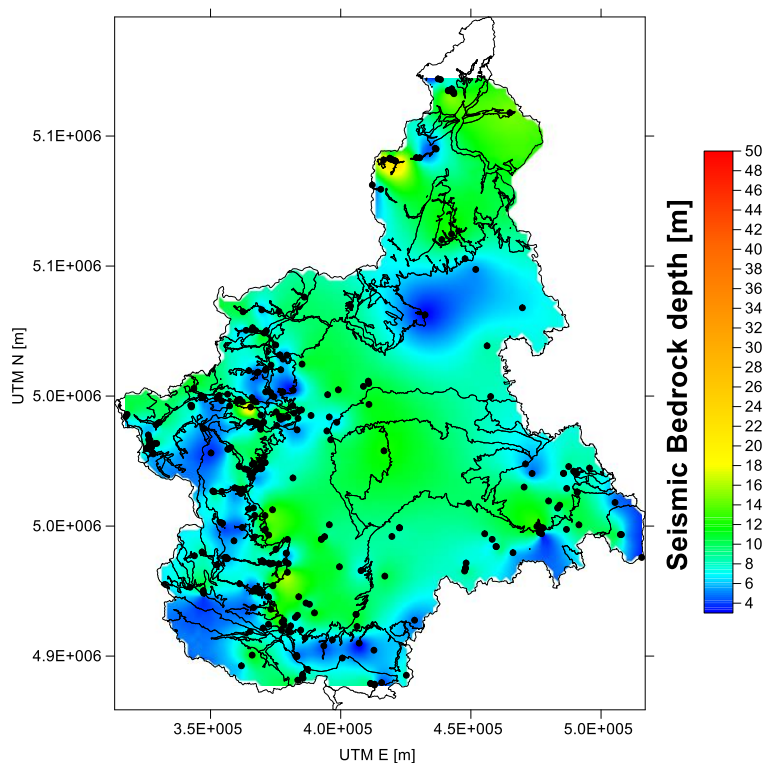



Figure 10. Geophysical information presented in the database: map of the estimated Seismic Bedrock depths.

The depth of the Geological Bedrock (Figure 9) shows a good correspondence with the attended Geological-Geomorphological
265 setting. Increasing bedrock depths are observed along the main alluvial plains (i.e. GGD 8, Po rive plain, and GGD 9, Apennine
plain) whereas the depth decreases along the Alpine chain and in the Oligo-Miocene (GGD 6) domain, that are those with
higher relief energy and therefore more eroded landscapes. The only exception to this model is the presence of the Alpine
valleys (GGD13) where the thickness of the valley floors deposits increases due to the glacial over-excavation (Figure 9). The
same feature is observed within GGD8 (Po River plain) where local increase of depths characterises the tectonically
270 downthrown buried structures (i.e. Savigliano Basin) and the buried continuation of the over-excavated glacial Alpine valleys
(Irace et al., 2009; Ivy-Ochs, et al., 2018).

Comparing the Geological Bedrock depth (Figure 9) and the Seismic Bedrock depth (Figure 10) maps, the last is generally
shallower than the former suggesting as the Vs profiles reach velocities of 800 m/s within the Cover Terrains, i. e. more packed
or cemented or coarser-grained layers. This is highly relevant for ground response analyses since usually materials having this
275 propagation velocity have a "rigid" behaviour. Nevertheless, the Seismic Bedrock map (Figure 10) still reports a setting
coherent with the geological information, showing reduced bedrock depths along the Alpine chain. However, the number of
data points in this last map is reduced with respect to the others (see also Table 4).

Finally, availability of Vs profiles in the presented database allowed also to represent at the regional scale the distribution of Vs,h according to NTC (Figure 11) and of Vs,30 (Figure 12), where Vs,h is the harmonic average shear-wave velocity down
280   to the depth h of the Seismic Bedrock, if this is reached within 30 m, otherwise h is 30m, and Vs,30 is the harmonic average shear-wave velocity down to the depth of 30 m.

The two maps show partially similar features. Particularly, GGD 7 (Pliocene Basins) is characterised by finer-grained low velocity Cover Terrains as already evidenced in the velocity distribution curves (see Figure 6). Similarly, GGD12 shows a clear velocity reduction contrasting with the coarser-grained and thick moraine deposits of GGD 10. The Vs,30 map (Figure
285   12) conversely better represents the average increased values of Vs within the Alpine Ridge GGDs, generally above 500 m/s. Also partially higher Vs,h and Vs,30 are observed within the GGD6 reflecting the presence of shallower geological and seismic bedrocks.

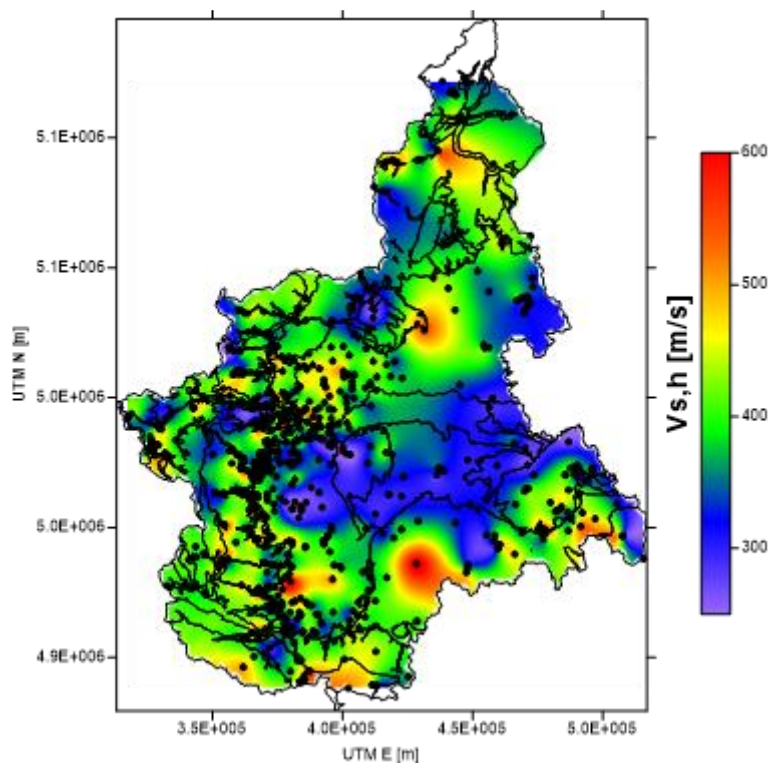



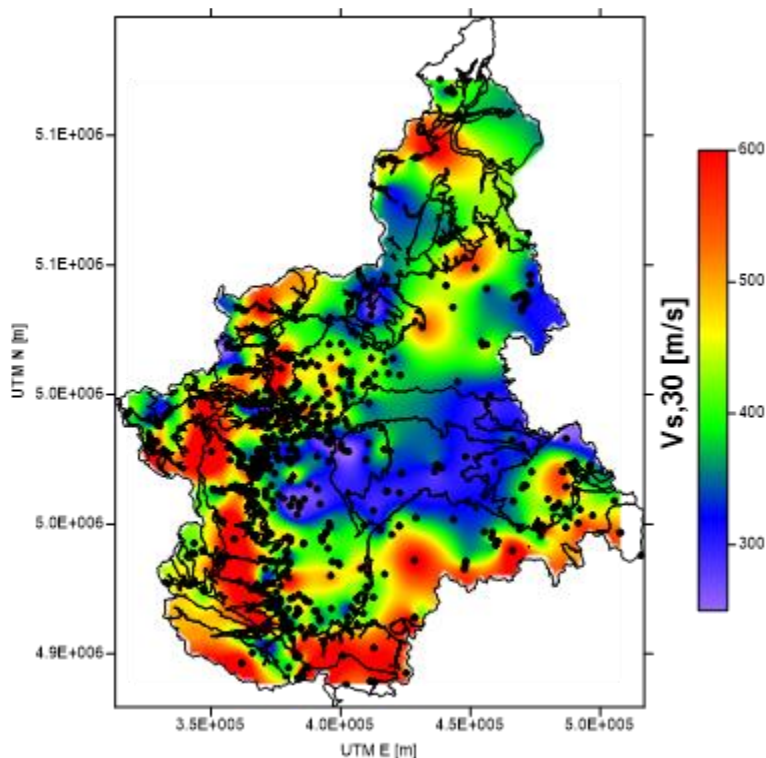
Figure 11. Geophysical information presented in the database: map of the Vs,h distribution.

290

Figure 12. Geophysical information presented in the database: map of the Vs,30 distribution.

At the regional scale similar attempts to map the ground zones having a homogeneous seismic response (i.e. De Ferrari et al., 2015) and a similar map of Vs,30 (i.e. Perrone et al., 2015) have been already conducted in the past. With respect to these previous literature papers the present work is based on a significantly increased data coverage (stratigraphical and seismic)

295 increasing the reliability of a regional view also including the Geological-Geomorphological modelling as a constraint for any further analysis, avoiding the only-seismic data driven approach, (i.e. De Ferrari et al., 2015) where geological information is only used for post interpretation. The confirmation of the coherence of the maps presented in the present study with the geological distribution is therefore a confirmation of the data quality and of the developed methodology.

The database presented in this work will be the starting point for further work, i.e. numerical simulations of the seismic ground

300 response over statistically representative samples of the different GGDs in order to produce "amplification abacuses" for the quantification of local stratigraphic amplifications of the seismic ground motion over the Region.

5 Data availability

The database provides insights into the geological and geophysical features of the Piedmont region in Northwest Italy. It includes the Geological-Geomorphological Database, the Geotechnical Database, and the Geophysical Database. The database

305 is referred to as Comina et al. (2024) and can be downloaded at https://doi.org/10.5281/zenodo.13685087.

Earth System
Science
Data

6 Conclusions

In this work a new extensive database of Vs profiles and geological technical properties of the cover terrains over the Piedmont Region (NW Italy) has been shown and presented. The data are obtained through a specific workflow developed for their evaluation at the regional scale, merging geological information and specific geophysical data collection. Therefore, this paper:

310   i) provide a new, extensive (i.e. containing more than 1000 profiles), database of Vs profiles to be used as the basis of randomization approaches also in different geological contexts; ii) provide, from specific analysis of this database, median properties of the different investigated geological units to be adopted as reference for similar materials in analogous geological contexts; and iv) provide, from specific analysis of this database, relevant parameters maps at the regional scale to be adopted for specific studies and or ground response regulations at the regional scale, iii) provide a workflow to be adopted for the same

315   aim for evaluation of Vs profiles distribution at the regional scale even in different case studies.

Author contributions

CC and PP designed the study. CC, PP, GMA, and CB performed the fieldwork. CC, PP, and GMA collected the data and assessed its quality. CC performed the analysis. CC and PP wrote the manuscript and created the figures. All authors contributed to the discussion and revision of the manuscript.

320   ## Competing interests

The contact author has declared that none of the authors has any competing interests.

Acknowledgments

Authors are indebted with the Sismic Sector of Piedmont Region for their support and data availability and with Techgea S.r.l. for the sharing of additional shear wave velocity profiles, fundamental to complement the data.

325   ## References

Aimar, M., Ciancimino, A., and Foti, S.: An assessment of the NTC18 simplified procedure for stratigraphic seismic site amplification prediction, Rivista Italiana di Geotecnica, 2019.

Ciancimino A., Cosentini R.M., Foti S., Lanzo G., Pagliaroli A., Pallara O.: The PoliTO–UniRoma1 database of cyclic and
330   dynamic laboratory tests: assessment of empirical predictive models, B. Earthq. Eng., 21 (5), pp. 2569 – 2601, 2023.

Ciancimino, A., Lanzo, G., Alleanza, G. A., Amoroso, S., Bardotti, R., Biondi, G., Cascone, E., Castelli, F., Di Giulio, A., and d'Onofrio, A.: Dynamic characterization of fine-grained soils in Central Italy by laboratory testing, Bull. Earthq. Eng., 18, 5503–5531, doi:10.1007/s10518-020-00866-0, 2020.

Comina, C., Foti, S., Boiero, D., and Socco, L.: Reliability of VS30 evaluation from surface-wave tests, J. Geotech.
Geoenviron. Eng., 137, 579-586, doi:10.1061/(ASCE)GT.1943-5606.0000478, 2011.

Comina, C., Foti, S., Passeri, F., and Socco, L. V.: Time-weighted average shear wave velocity profiles from surface wave
tests through a wavelength-depth transformation, Soil Dyn. Earthq. Eng., 158, 107262, doi:10.1016/j.soildyn.2022.107262,
2022.

Comina, C., Adinolfi, G. M., Bertok, C., Bertea, A., Giraud, V., and Pieruccini, P.: Regional scale shear wave velocity profiles
for ground response analyses uncertainties evaluations – the Piedmont Region (NW Italy) Database, Zenodo [data set],
https://doi.org/10.5281/zenodo.13685087, 2024.

Darendeli, M. B.: Development of a new family of normalized modulus reduction and material damping curves, PhD
Dissertation, University of Texas at Austin, 2001.

De Ferrari, R., Ferretti, G., Bosco, F., and Gaeta, A. R.: Calibration of a VS30 map for shaking-map production in Piedmont
(Italy), Near Surface Geoscience 2015 - 21st European Meeting of Environmental and Engineering Geophysics, 356–360,
2015.

EPRI: Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of
Fukushima Near-Term Task Force Recommendation 2.1: Seismic, EPRI, Report 1025287, Palo Alto, CA, 2013.

Gaudiosi, I., Romagnoli, G., Albarello, D., Fortunato, C., Imprescia, P., Stigliano, F., and Moscatelli, M.: Shear modulus
reduction and damping ratios curves joined with engineering geological units in Italy, Sci. Data, 10, art. no. 625,
doi:10.1038/s41597-023-01936-3, 2023.

Geoportale ARPA: [Online] Available at:
https://webgis.arpa.piemonte.it/agportal/apps/webappviewer/index.html?id=2067aa1af4aa44a5a6855a9d30cb5467.

Gianotti, F., Forno, M. G., Ivy-Ochs, S., Giovanni, M., and Cesare, R.: Stratigraphy of the Ivrea morainic amphitheatre (NW
Italy). An updated synthesis, Alp. Medit. Quat., 28, 29–58, 2015.

Irace, A., Clemente, P., Natalicchio, M., Ossella, L., Trenkwalder, S., De Luca, D. A., Mosca, P., Piana, F., Polino, R., and
Violanti, D.: Geologia e idrostratigrafia profonda della Pianura Padana occidentale, La Nuova Lito Firenze, ISBN 978-88-
904554-0-7, 111 pages, 2009.

Ivy-Ochs, S., Lucchesi, S., Baggio, P., Fioraso, G., Gianotti, F., Monegato, G., Graf, A., Akcar, N., Christl, M., and Carraro,
F.: New geomorphological and chronological constraints for glacial deposits in the Rivoli-Avigliana end-moraine system and
the lower Susa Valley (Western Alps, NW Italy), J. Quat. Sci., 33, 550–562, doi:10.1002/jqs.3061, 2018.

Moss, R. E. S.: Quantifying measurement uncertainty of thirty-meter shear-wave velocity, Bull. Seismol. Soc. Am., 98, 1399-
1411, doi:10.1785/0120070096, 2008.

Pagani, M., Marcellini, A., Crespellani, T., Martelli, L., Tento, A., and Daminelli, R.: Seismic microzonation regulations of
the Emilia-Romagna Region (Italy), Third Int. Symp. Effects Surf. Geol. Seism. Mot., Grenoble, France, 30 August–1
September, 2006.

Passeri, F., Foti, S., and Rodriguez-Marek, A.: A new geostatistical model for shear wave velocity profiles, Soil Dyn. Earthq.
Eng., 136, 106247, doi:10.1016/j.soildyn.2020.106247, 2020.

Passeri, F., Comina, C., Foti, S., and Socco, L. V.: The Polito Surface Wave flat-file Database (PSWD): statistical properties
of test results and some inter-method comparisons, Bull. Earthq. Eng., 19, 2343–2370, doi:10.1007/s10518-021-01094-1,
2021.

Perrone, G., Riccardo Gaeta, A., Tiranti, D., Cadoppi, P., and Fioraso, G.: Ground zoning map of the Piedmont region (NW
Italy): Methodology and preliminary results, Eng. Geol. Soc. Territ. Vol. 5, 1065–1069, doi:10.1007/978-3-319-09048-1_206,
2015.

375 Peruzzi, G., Albarello, D., Baglione, M., D'Intinosante, V., Fabbroni, P., and Pileggi, D.: Assessing 1D litho-stratigraphical amplification factor for microzoning studies in Italy, Bull. Earthq. Eng., 14, 373–389, doi:10.1007/s10518-015-9801-5, 2016.

Piana, F., Fioraso, G., Irace, A., Mosca, P., d'Atri, A., Barale, L., Falletti, P., Monegato, G., Morelli, M., Tallone, S., and Vigna, G. B.: Geology of Piemonte region (NW Italy, Alps–Apennines interference zone), J. Maps, 13(2), 395–405, doi:10.1080/17445647.2017.1339742, 2017a.

380 Piana, F., Barale, L., Compagnoni, R., d'Atri, A., Fioraso, G., Irace, A., Mosca, P., Tallone, S., Monegato, G., and Morelli, M.: Geological Map of Piemonte Region at 1:250,000 scale Explanatory Notes, Acc. Sc. Torino Memorie Sc. Fis., 41, 3-143, 2017b.

Piana, F., Barale, L., Compagnoni, R., d'Atri, A., Fioraso, G., Irace, A., Mosca, P., Tallone, S., Morelli, M., and Vigna, G. B.: Carta Geologica del Piemonte – Geological Map of Piemonte, 2nd edition, CNR-IGG, ARPA Piemonte, Accademia delle 385 Scienze di Torino, 2020.

Pieruccini, P., Paolucci, E., Fantozzi, P. L., Naldini, D., and Albarello, D.: Effectiveness of Geological-Geomorphological modelling for Seismic Microzonation studies, Nat. Hazards, 112, 451–474, doi:10.1007/s11069-022-05426-3, 2022.

Romagnoli, G., Tarquini, E., Porchia, A., Catalano, S., Albarello, D., and Moscatelli, M.: Constraints for the Vs profiles from engineering-geological qualitative characterization of shallow subsoil in seismic microzonation studies, Soil Dyn. Earthq. 390 Eng., 161, doi:10.1016/j.soildyn.2022.107703, 2022.

Shi, J., and Asimaki, D.: A generic velocity profile for basin sediments in California conditioned on VS30, Seismol. Res. Lett., 89, 1397–1409, doi:10.1785/0220180057, 2018.

Stewart, J. P., Klimis, N., Savvaidis, A., Theodoulidis, N., Zargli, E., Athanasopoulos, G., Pelekis, P., Mylonakis, G., and Margaris, B.: Compilation of a local VS profile database and its application for inference of VS30 from geologic-and terrain-395 based proxies, Bull. Seismol. Soc. Am., 104, 2827-2841, doi:10.1785/0120140114, 2014.

Toro, G. R.: Probabilistic models of the site velocity profiles for generic and site–specific ground–motion amplification studies, Appendix in Technical Rep. No. 779574, Brookhaven National Laboratory, Upton, NY, 1995. Available at: http://pacificengineering.org/bnl/Bnl_rpt.zip.

Toro, G. R.: Site-wide probabilistic model of shear-wave velocity profiles at the Savannah River Site, Aiken, South Carolina, 400 Report by Risk Engineering, Inc. to Bechtel Savannah River Co., Report Number WSRC-OS-2006–00514, Revision 1, doi:10.13140/RG.2.2.34012.46727, 2005.

Toro, G. R.: Uncertainty in Shear-Wave Velocity Profiles, J. Seismol., 26, 713–730, doi:10.1007/s10950-022-10024-6, 2022.

Vucetic, M., and Dobry, R.: Effect of soil plasticity on cyclic response, J. Geotech. Eng., 117, 89–107, doi:10.1061/(ASCE)0733-9410(1991)117:1(89), 1991.

405 Wang, P., Zimmaro, P., Ahdi, S. K., Kwak, D. Y., and Stewart, J. P.: Shear Wave Velocity Database and Its Application for Analysis of Non-Ergodic Site Amplification Effects, Report supported by the US Geological Survey, California Strong Motion Instrumentation Program, and Consortium of Organizations for Strong Motion Observation Systems.

Wang, Y., and Stokoe, K.: Development of constitutive models for linear and nonlinear shear modulus and material damping ratio of uncemented soils, J. Geotech. Geoenviron. Eng., 148, 04021192, doi:10.1061/(ASCE)GT.1943-5606.0002684, 2022.