The XVII European Conference on
Soil Mechanics and Geotechnical Engineering
Reykjavik Iceland
1 - 6 September 2019

RECENT DEVELOPMENTS IN SEISMIC SITE RESPONSE EVALUATION AND MICROZONATION

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Outline

- Introduction: Seismic Site Response during the 2016 Central Italy EQ
- Seismic Microzonation in Italy (URBAN-SCALE)
  - ✓ Microzonation of Central Italy
  - ✓ The case study of Montedinove
- Uncertainties in Ground Response Analyses (SINGLE-SITE)
  - ✓ Application for a site in Roccafluvione
- Final Remarks

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Geotechnical Extreme Events Reconnaissance (GEER)

2016 CENTRAL ITALY EARTHQUAKE SEQUENCE

http://www.geerassociation.org/

Event Date	:	08-24-2016
Location	:	Central Italy
Report Date	:	09-15-2016
Event Category	:	Earthquake
Sequence of Events	:	Yes
EQ Magnitude	:	INGV 6.0, 5.9, 6.5
Report Number	:	GEER-050
DOI	:	doi:10.18118/G61S3Z
Event Latitude	:	42.69561

File Title	File Version	File Date
Report Part 1 - 24 August event	Version 1	09-15-2016
Table S1	Version 1	11-22-2016
Table S2	Version 1	11-22-2016
Report Part 1 - 24 August event	Version 2	11-22-2016
Report Part 2 - October events	Version 1	01-09-2017
Report Part 2 - October events	Version 2	05-08-2017
Electronic Supplement to Chapter 3	Version 1	05-08-2017
Table S1	Version 2	05-08-2017

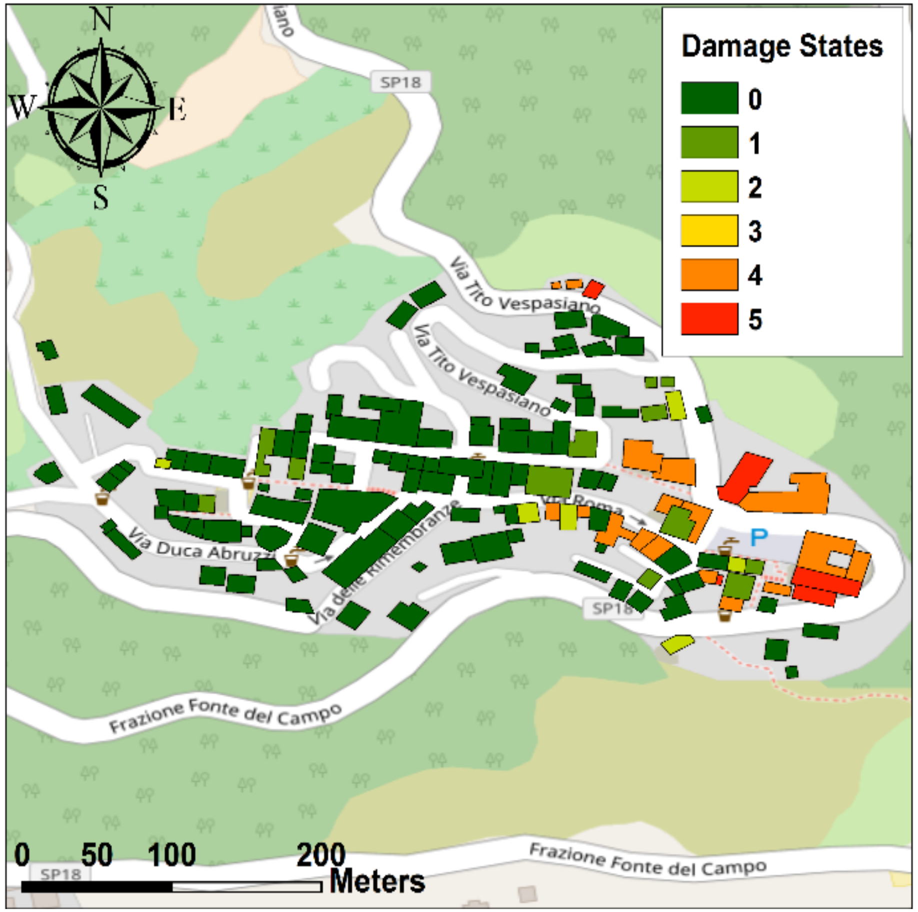
Accumoli: August vs. October

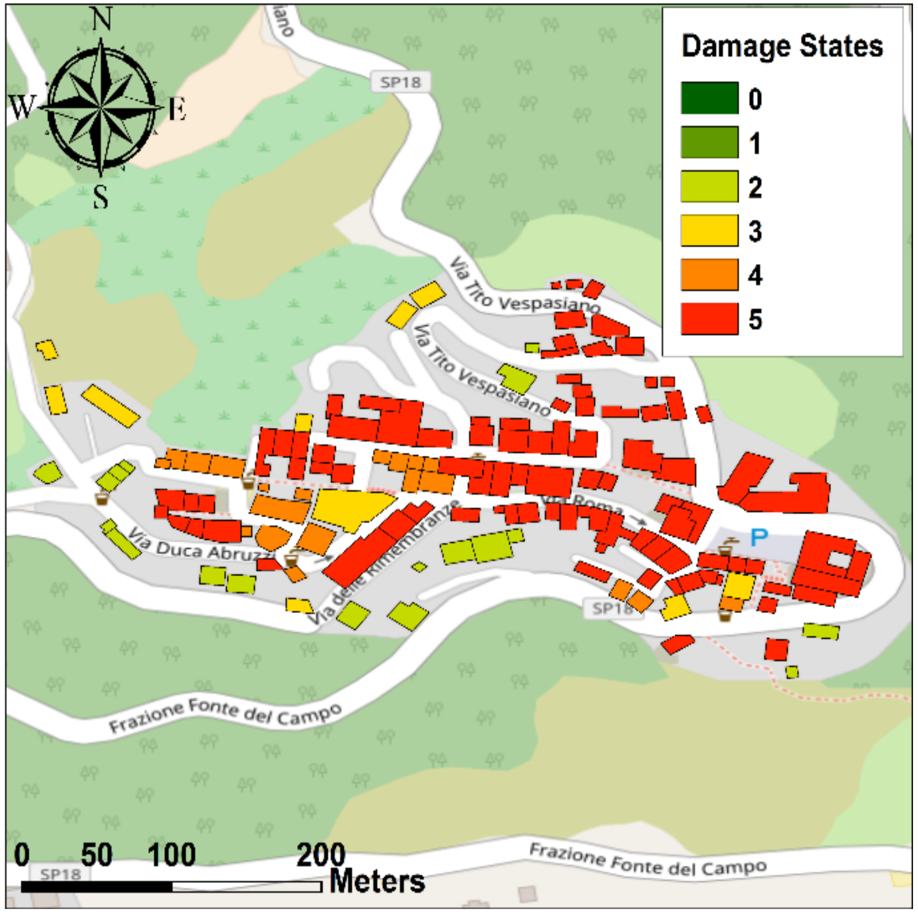
The Town Hall

San Francis square

Accumoli: August vs. October

Estimated peak ground acceleration: 0,56 g in August 2016 EQ and 0,45 g in October 2016 EQs, the latter caused almost total collapse after localised damage suffered in August.



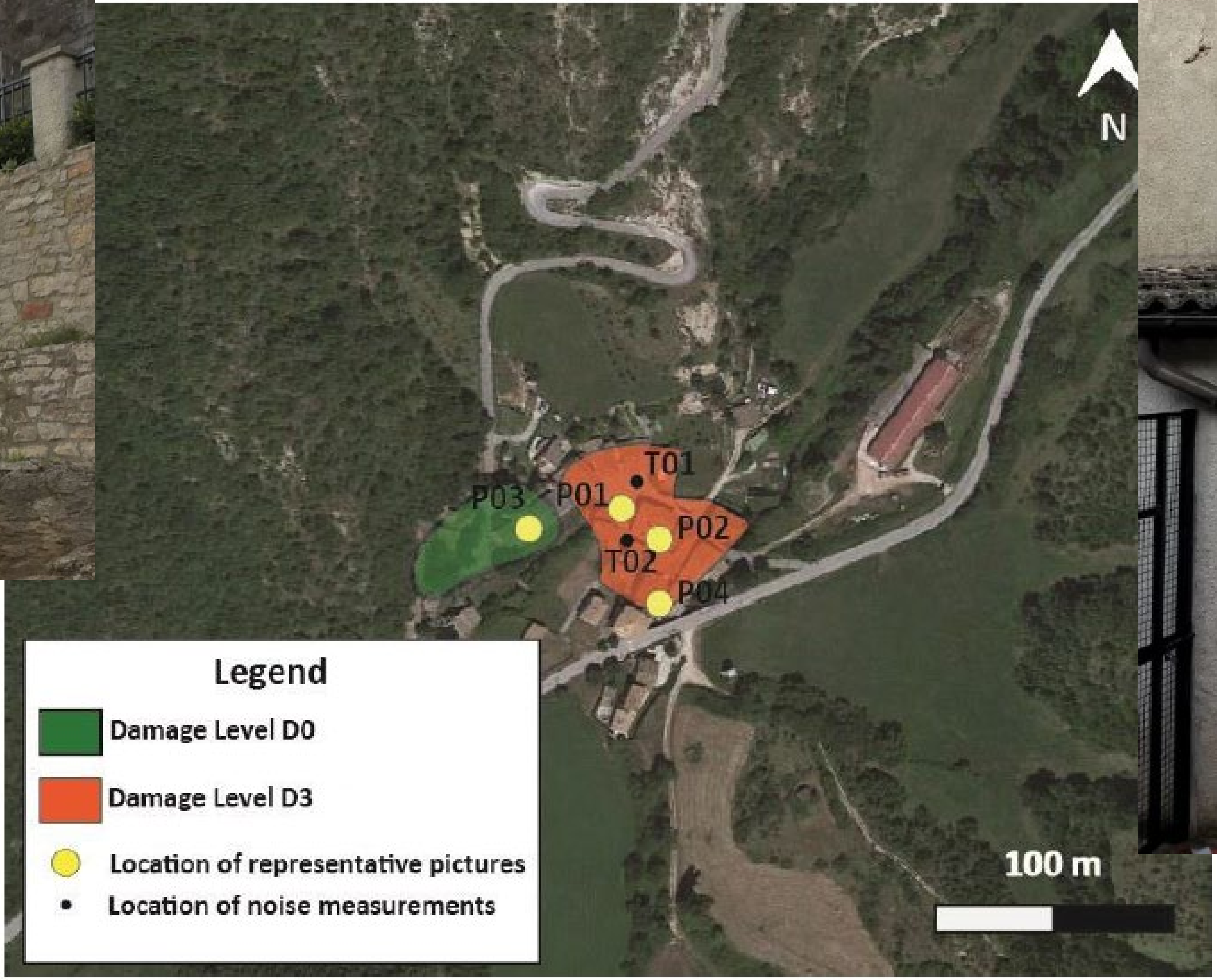


Incremental damage patterns after August 2016 (left) and October 2016 (right) events

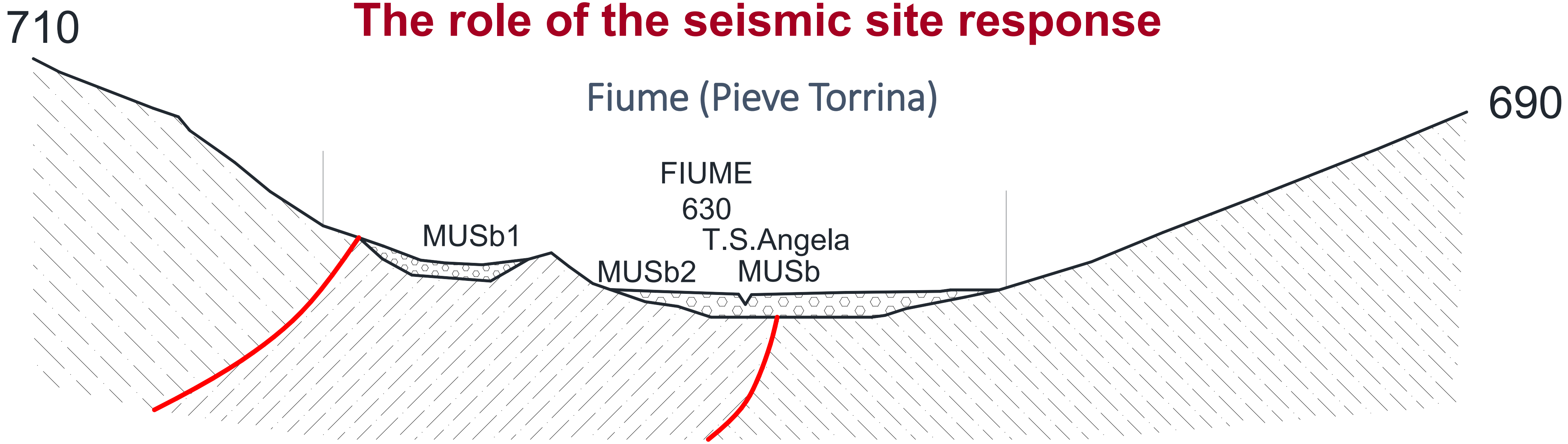
Accumoli: drone reconnaissance after the October 2016 EQ

The role of the seismic site response

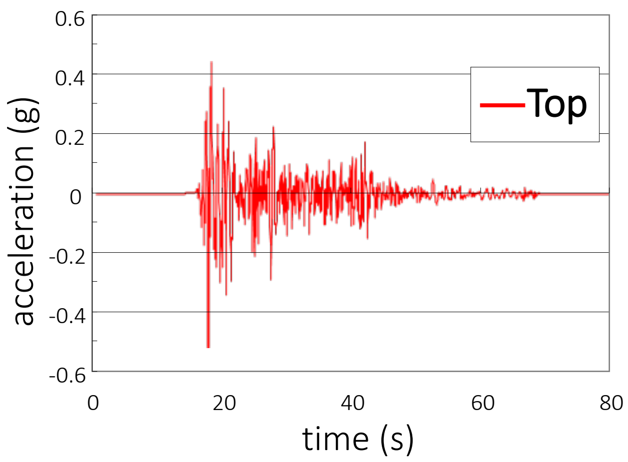
Fiume (Pieve Torrina)

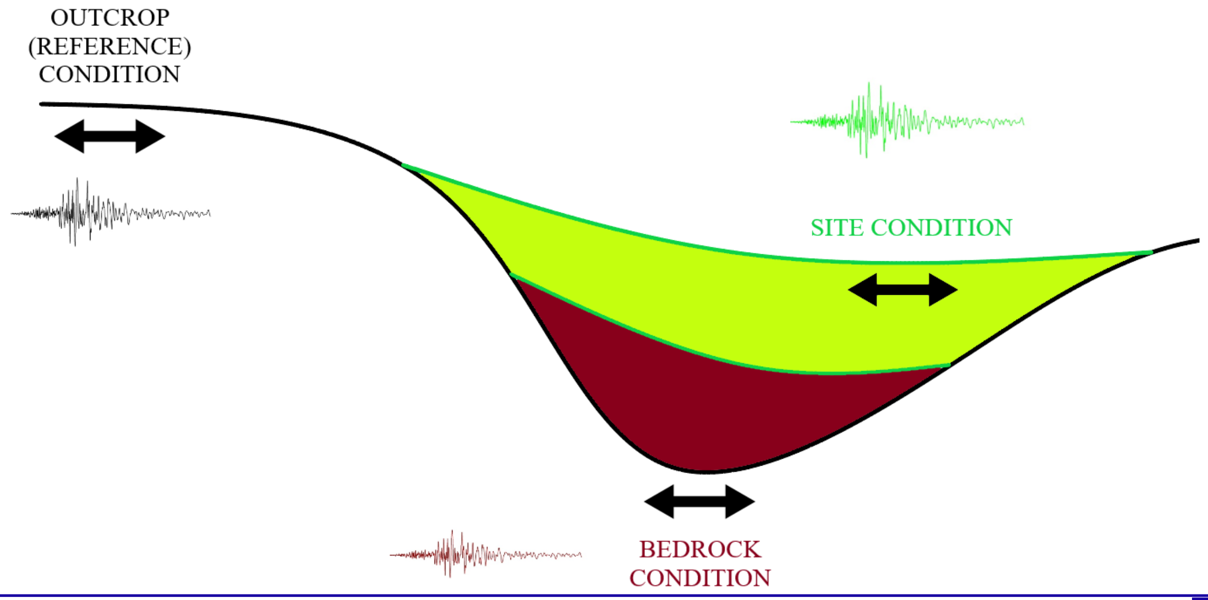


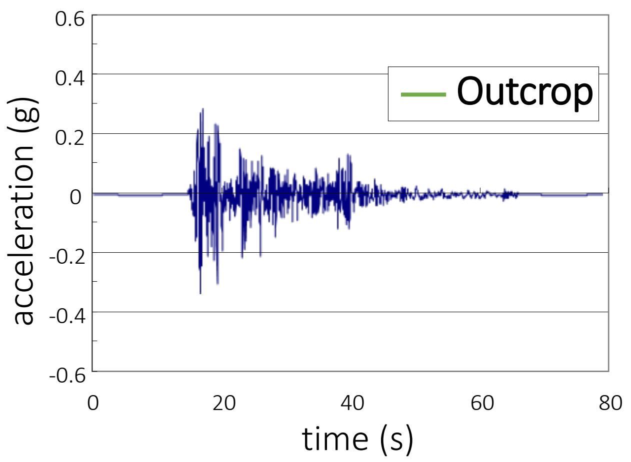
The role of the seismic site response



Typical condition for a stratigraphic ground motion amplification

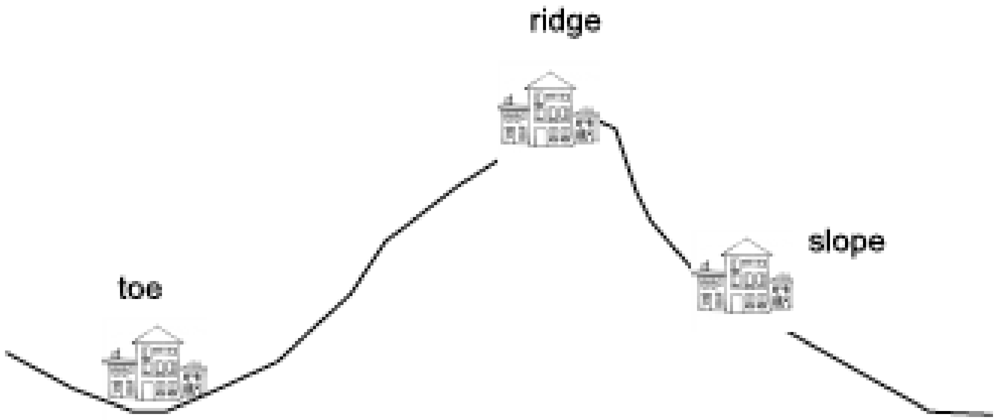




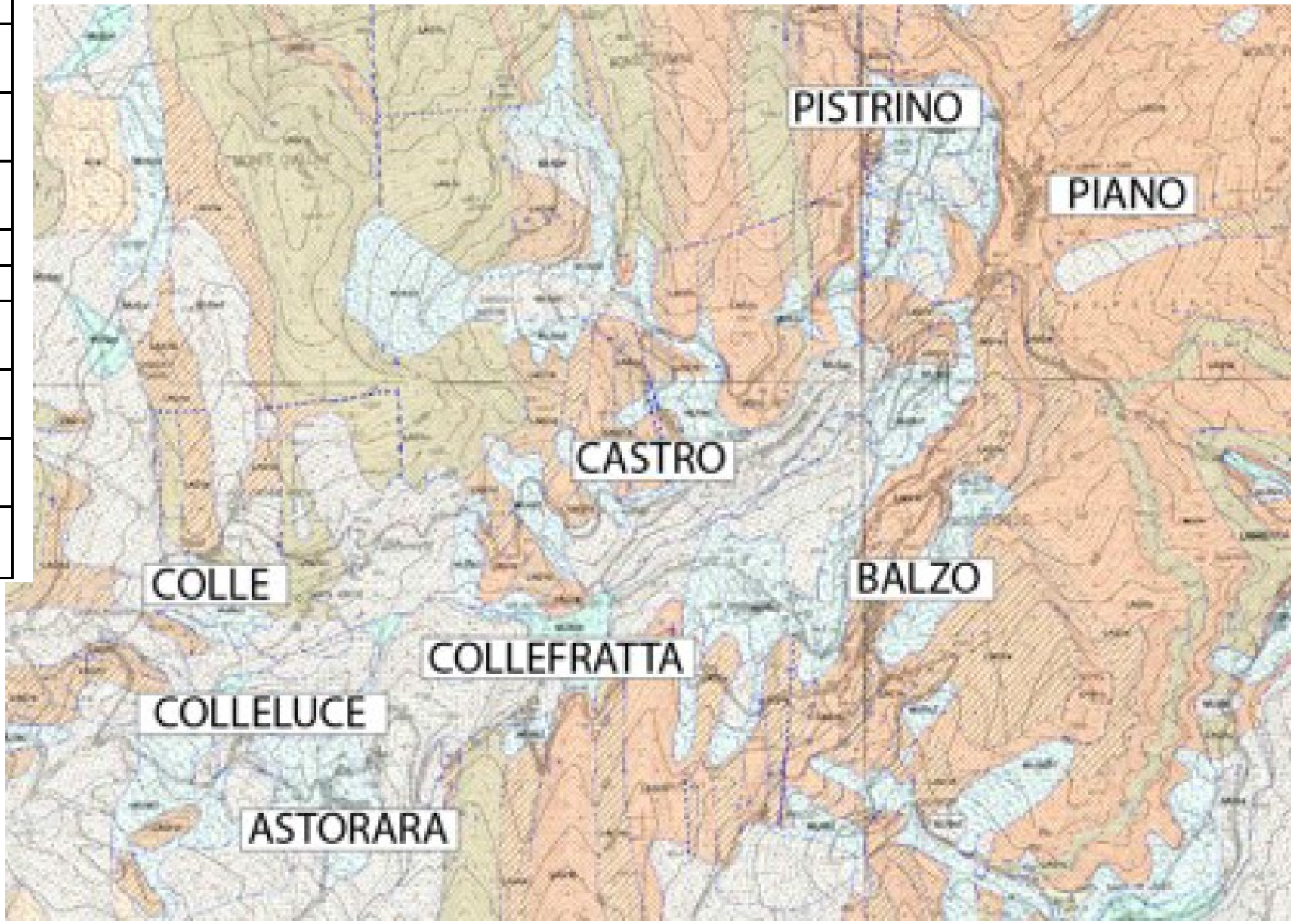


The role of the seismic site response

#	Hamlet	Geological setting	Active landslides	Topograhic features (see Fig. 5.81)	Structures (see Table 5.22)	Average damage level
1	Astorara	Laga Flysch, pelitic-arenaceous facies**	no	slope	P13-P14	D0-D1
2	Balzo	Laga Flysch, pelitic-arenaceous facies	no	ridge	-	-
3	Castro	Laga Flysch, pelitic-arenaceous facies	yes	ridge	P15-P18	D3-D4
4	Colle	Laga Flysch, arenaceous facies	no*	slope	P01- P03	D2-D3
5	Collefratte	eluvial-colluvial deposits	yes	ridge	P19-P20	D2-D3
6	Colleluce	eluvial-colluvial deposits	yes	slope	P21-P22	D1-D2
7	Piano	Laga Flysch, pelitic-arenaceous facies	no	toe	P10-P11	D0-D1
8a	Pistrino (lower part)	eluvial-colluvial deposits**	yes	slope	P04-P06	D2-D3
8b	Pistrino (upper part)	eluvial-colluvial deposits**	yes	slope	P07-P09	D0-D1
9	Propezzano	Laga Flysch, arenaceous facies	no	ridge	P12	-



Montegallo








Montegallo

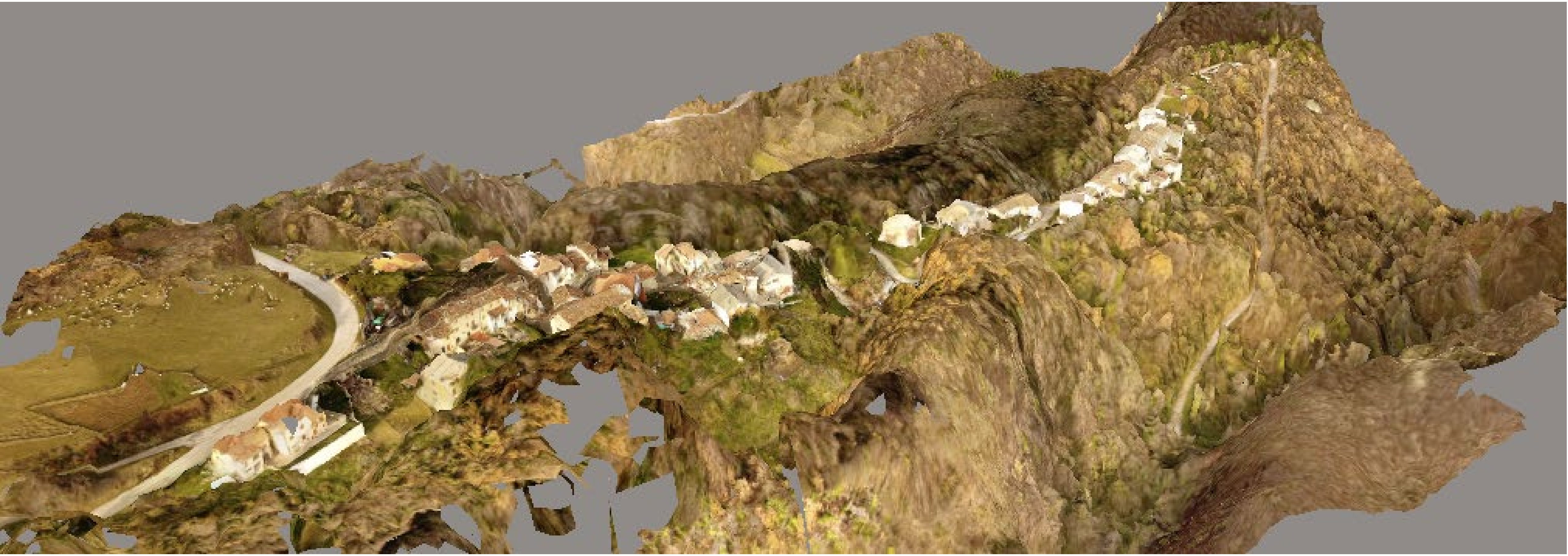
Piano: D0 after both the mainshocks (also for highly vulnerable structures)

Pistrino:
Different levels of damage for buildings a few hundred meters away
In Pistrino di sopra, also highly vulnerable structures have suffered low damages

Castro: stratigraphic/topographic amplification
D2-3 after August
D4-5 after October

Montegallo: the Castro hamlet

An emblematic example of topographic amplification



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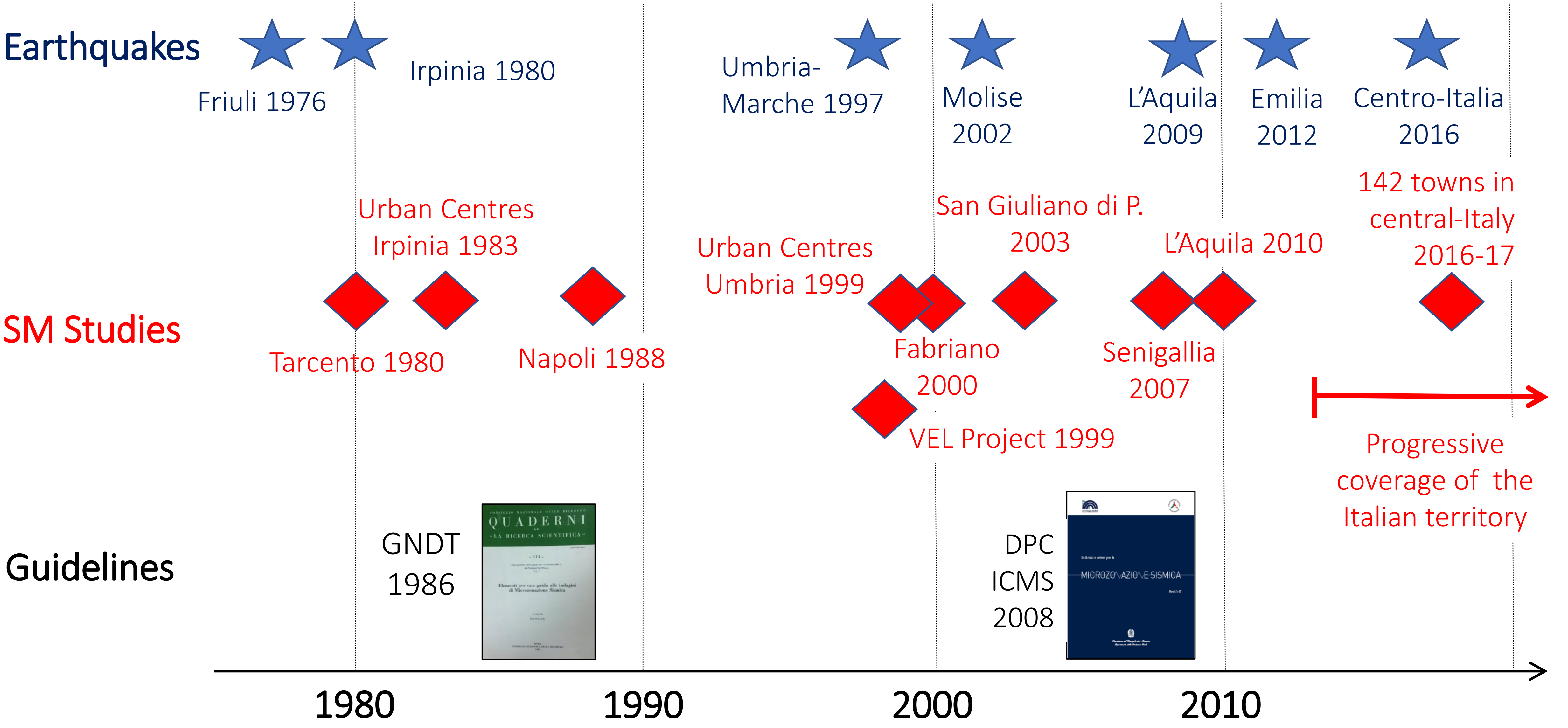
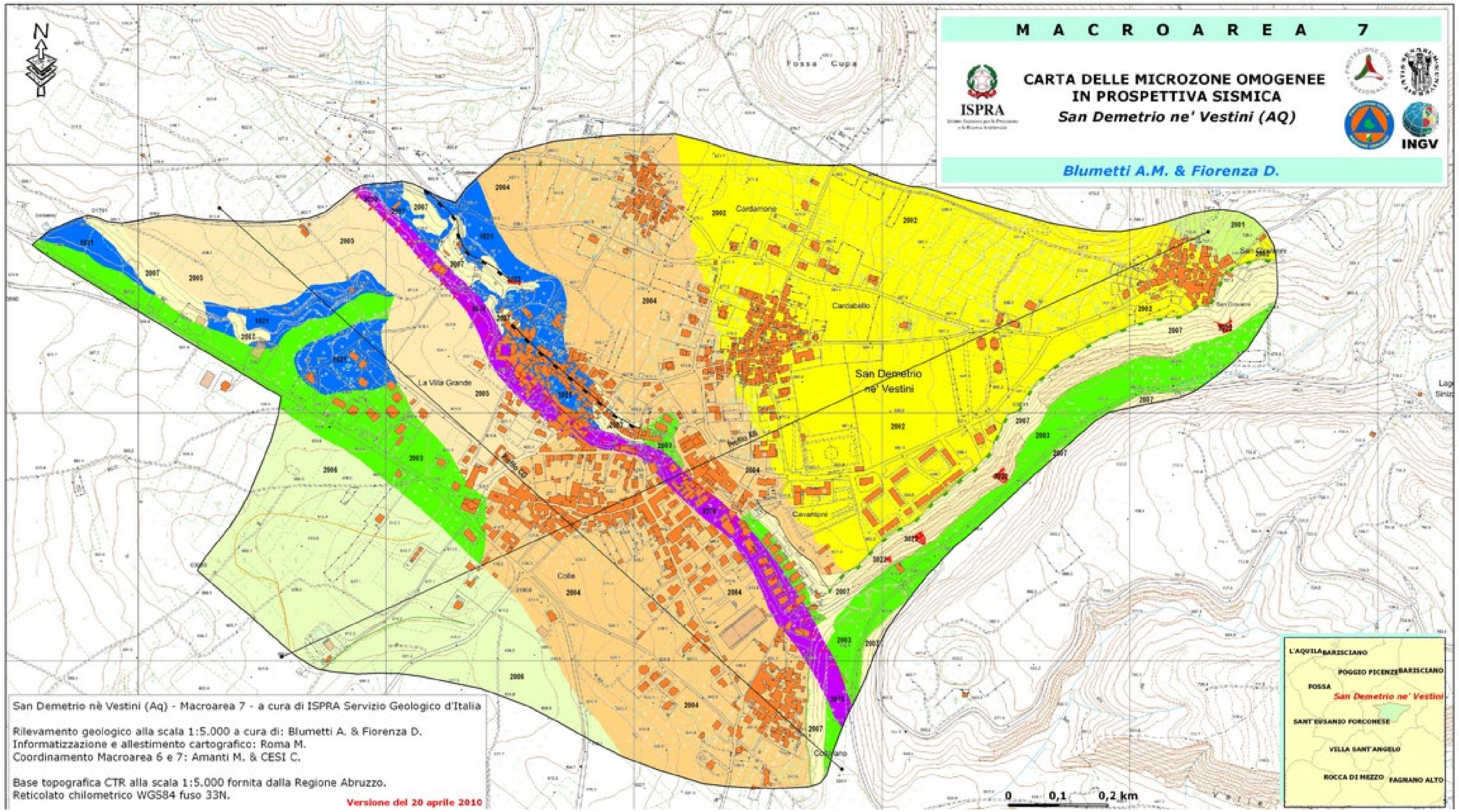
Seismic Microzonation in Italy



(modified after Crespellani, 2014)

Seismic Microzonation: a multidisciplinary process



The main objective: MOPS (map of the homogeneous areas from the seismic perspective):

- ✓ Expected instabilities (e.g. liquefaction, slope instabilities, fault ruptures)
- ✓ Expected level of ground shaking amplification

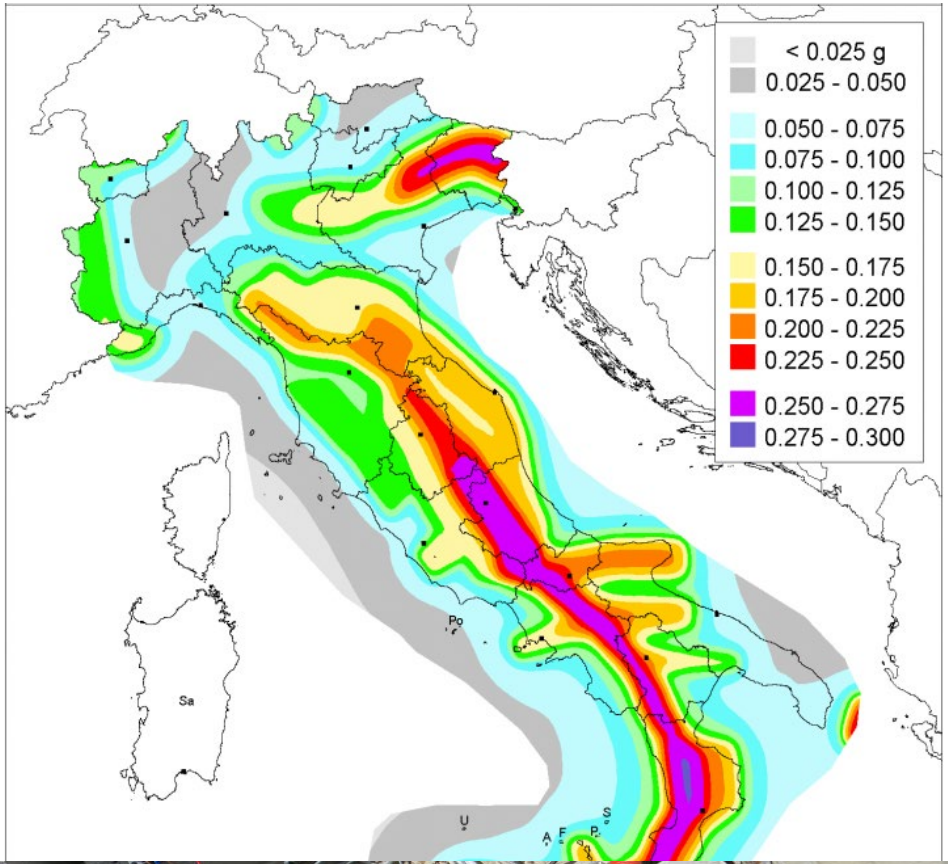
Seismic Microzonation: a multidisciplinary process

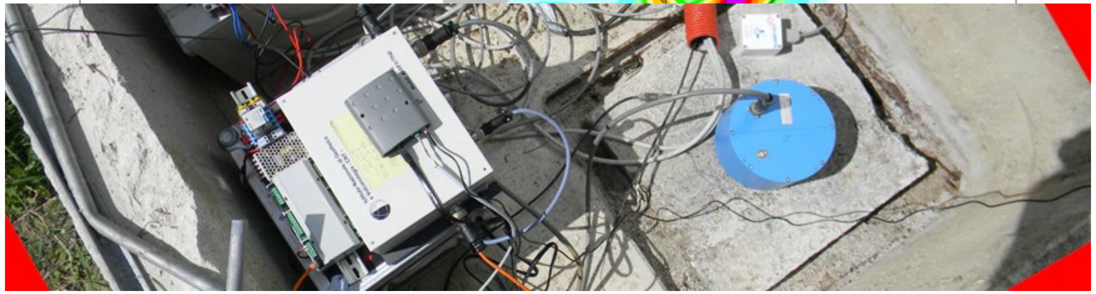
1) Geomatics and Topography

- High-definition mapping of the 3D territory

2) Seismology

- Identification of the active seismic sources/faults
- Definition of the seismic hazard
- Processing of the recorded motions





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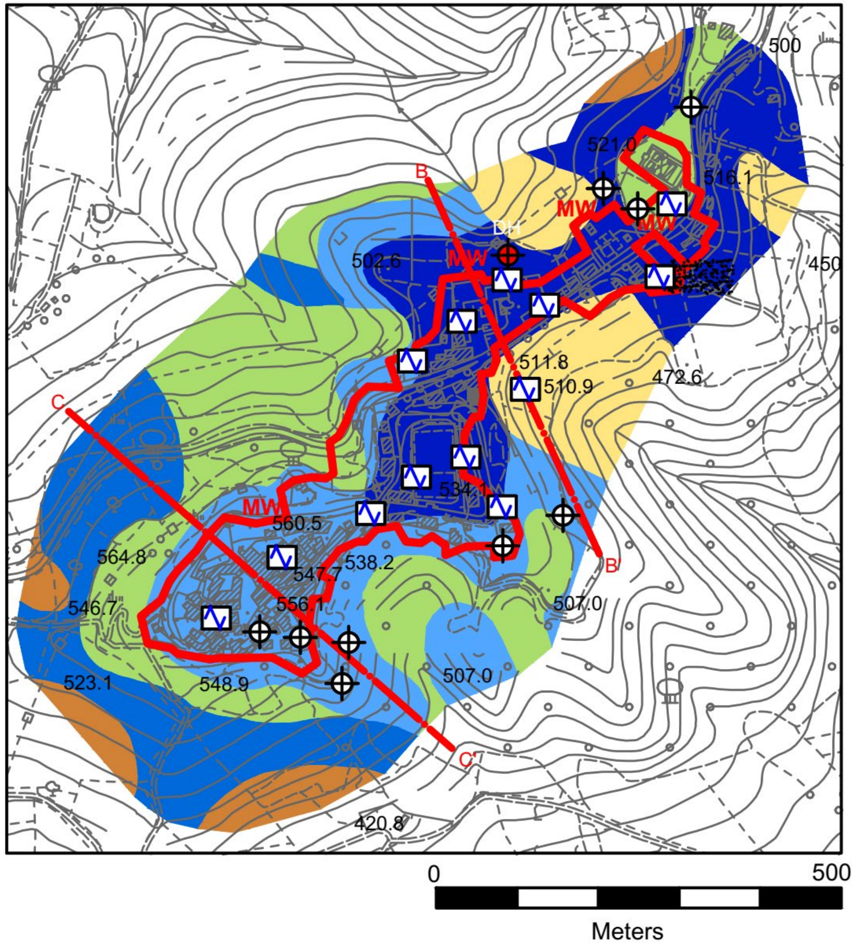
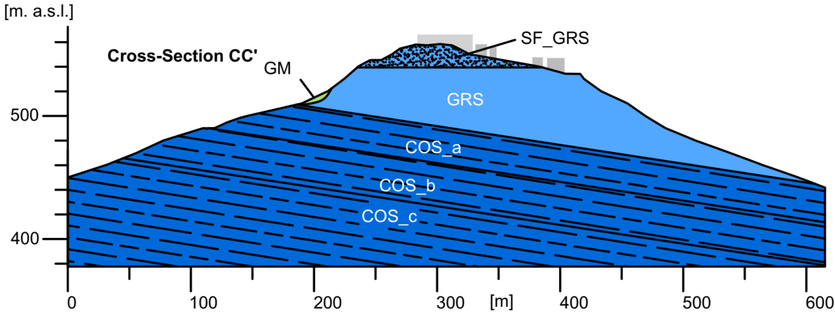


3) Engineering Geology

- Soil and Rock geological classification
- Outcrop mapping
- Landslides/instabilities detection



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4) Applied Near-Surface Geophysics

- Non-invasive/Surface wave tests (active and passive methods)
- Invasive tests

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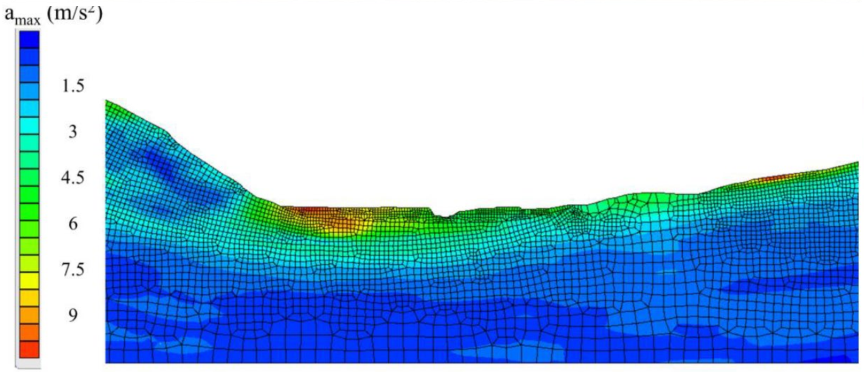

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4) Applied Near-Surface Geophysics

- Non-invasive/Surface wave tests (active and passive methods)
- Invasive tests

5) Geomechanics and Geotechnical Earthquake Engineering

- Laboratory geomechanical tests (static and cyclic)
- Numerical models

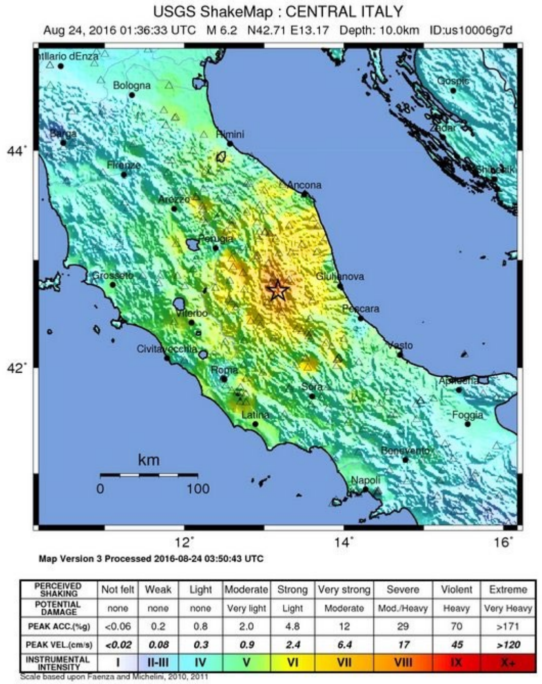
Microzonation of Central Italy

To support a national plan for the reduction of seismic risk, the **Italian Department of Civil Protection** in agreement with **Regional Administrations**, promoted a multi-year project devoted to implement seismic microzonation in the current practice of city planning

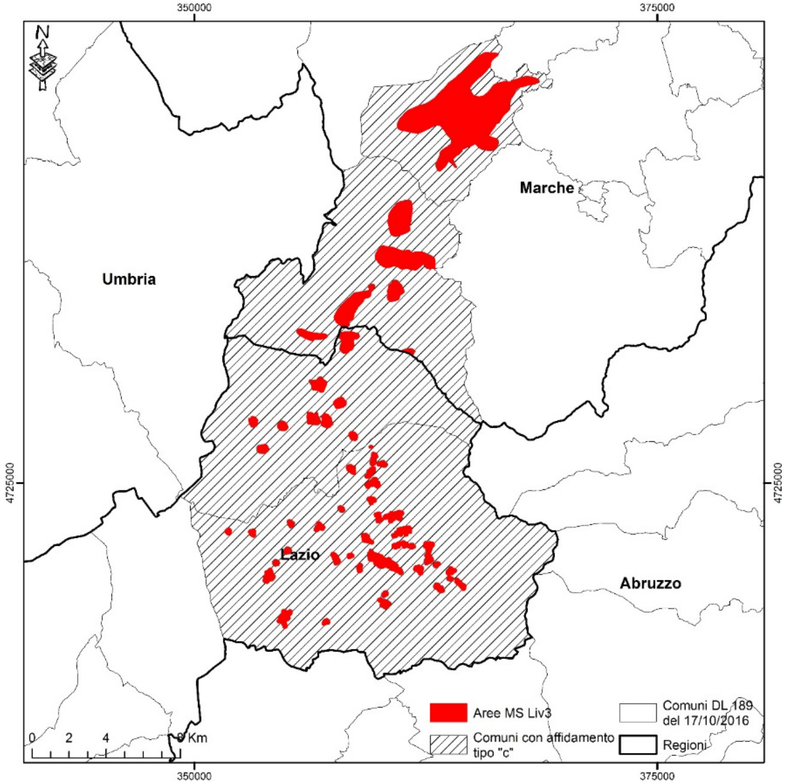
To support authorities from the technical point of view, the **Centre for Seismic Microzonation and its applications** (hereafter Centre) has been established, which includes most of the scientific Institutions operating in Italy in the field seismic hazard assessment

25 Research Institutions and Universities: geologists, seismologists, and engineers

Microzonation of Central Italy



Since the beginning of the seismic sequence that affected central Italy starting form August 2016, the Centre has been charged for coordinating microzonation activities supporting reconstruction in the damaged settlements



Phase 1. Seismic microzonation of Amatrice, Arquata del Tronto, Accumoli, Montegallo

The study was carried out by Centre for the Italian Department of Civil Protection, September-November 2017

More than 500 researchers per week involved

More than 1000 geophysical prospections done

More than 50 temporary seismic stations installed

New 1:5000 scale geological maps produced

Hundreds 1D and 2D numerical analyses delivered

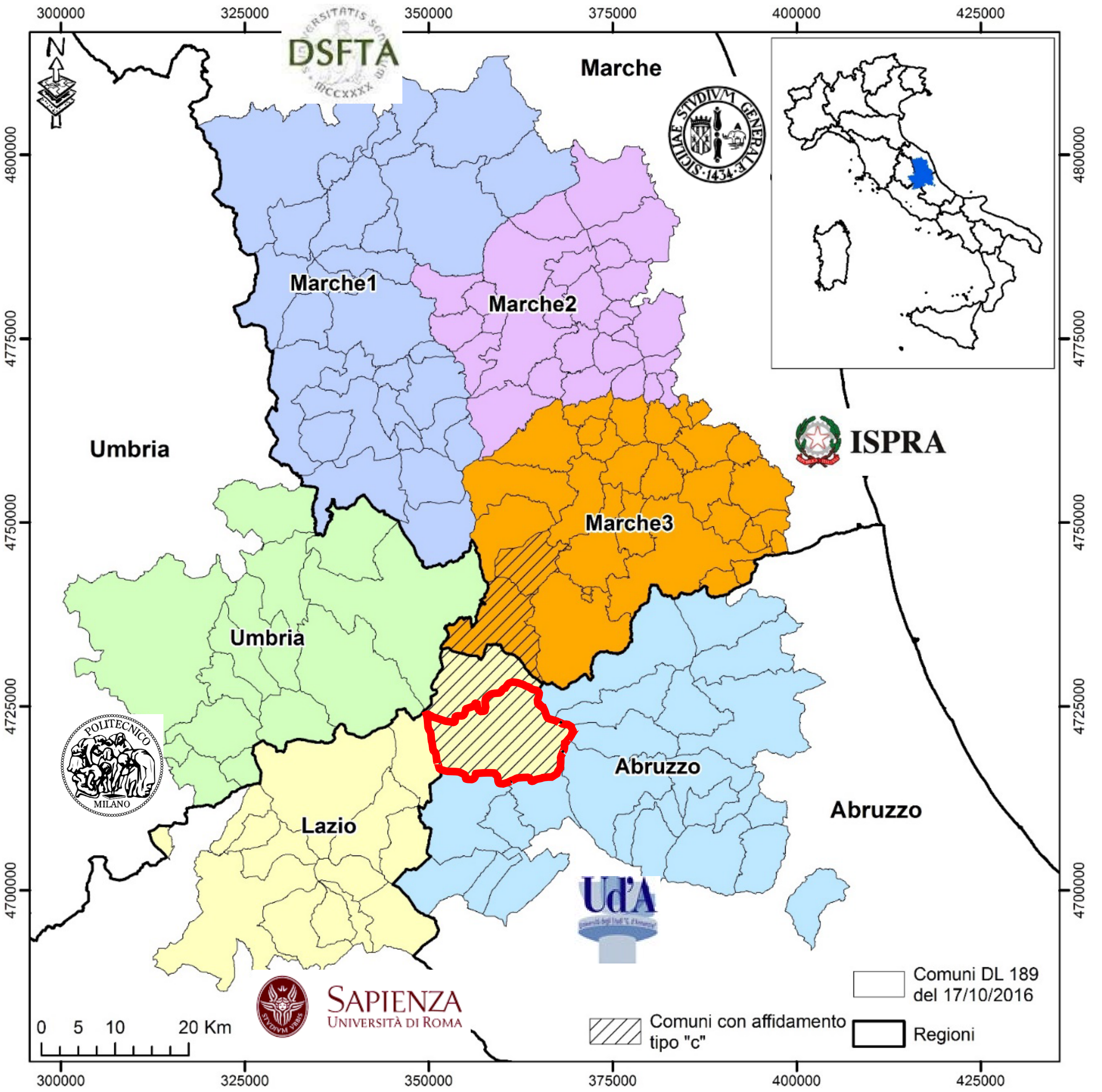
Microzonation of Central Italy

Phase 2. Seismic microzonation of **138 Municipalities**, May-December 2018:

- Abruzzo, 23 Municipalities
- Lazio, 15 Municipalities
- Marche 1, 25 Municipalities
- Marche 2, 30 Municipalities
- Marche 3, 30 Municipalities
- Umbria, 15 Municipalities

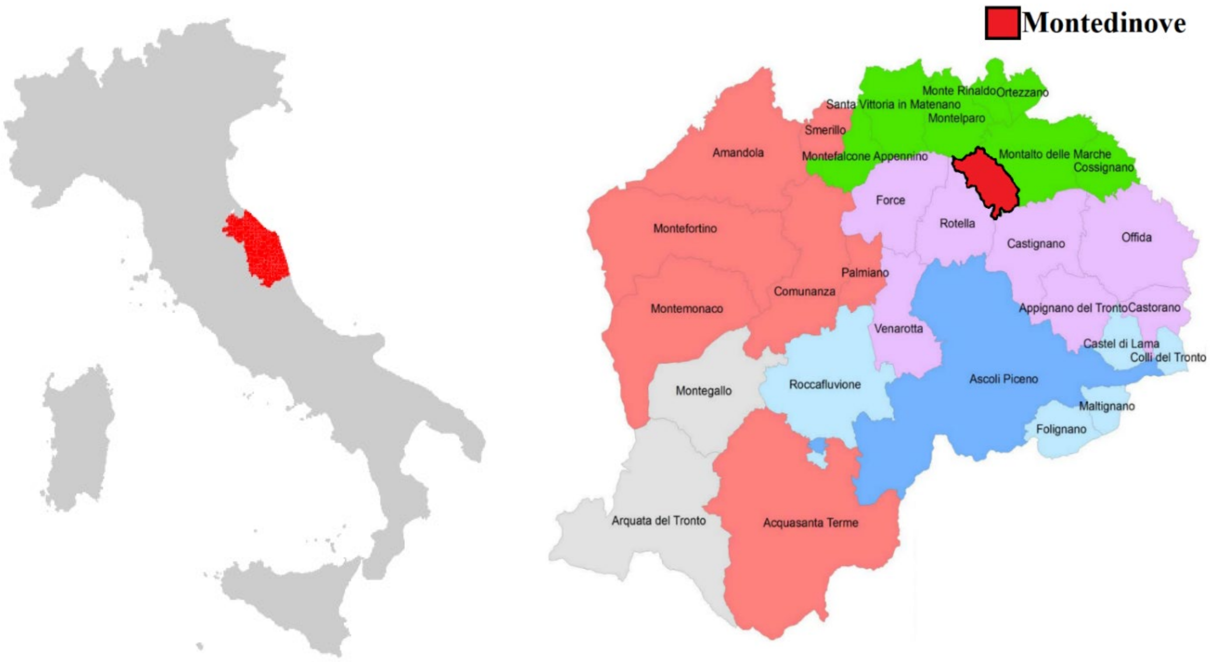
More than 500.000 citizens involved

Studies were funded by the Government Commissioner and performed by practitioners (114 groups) with the support of the Centre for Seismic Microzonation and its applications



The case study of Montedinove

A case in point is represented by the SM study carried out at the **Montedinove** municipality, in the province of Ascoli Piceno, Marche region.



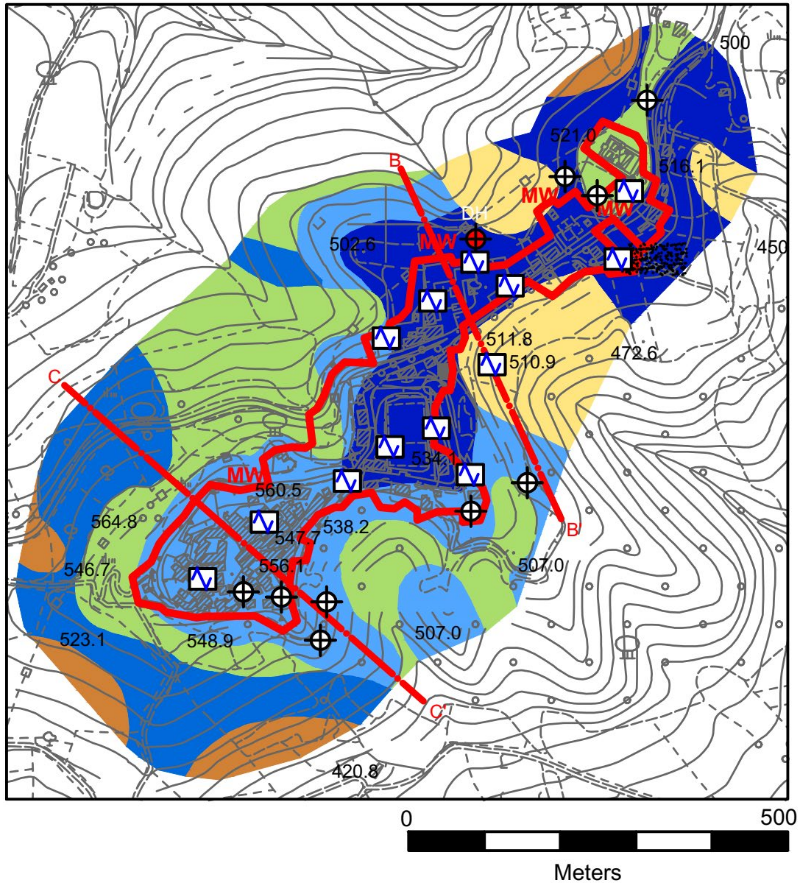
Further details about the case study can be found in:

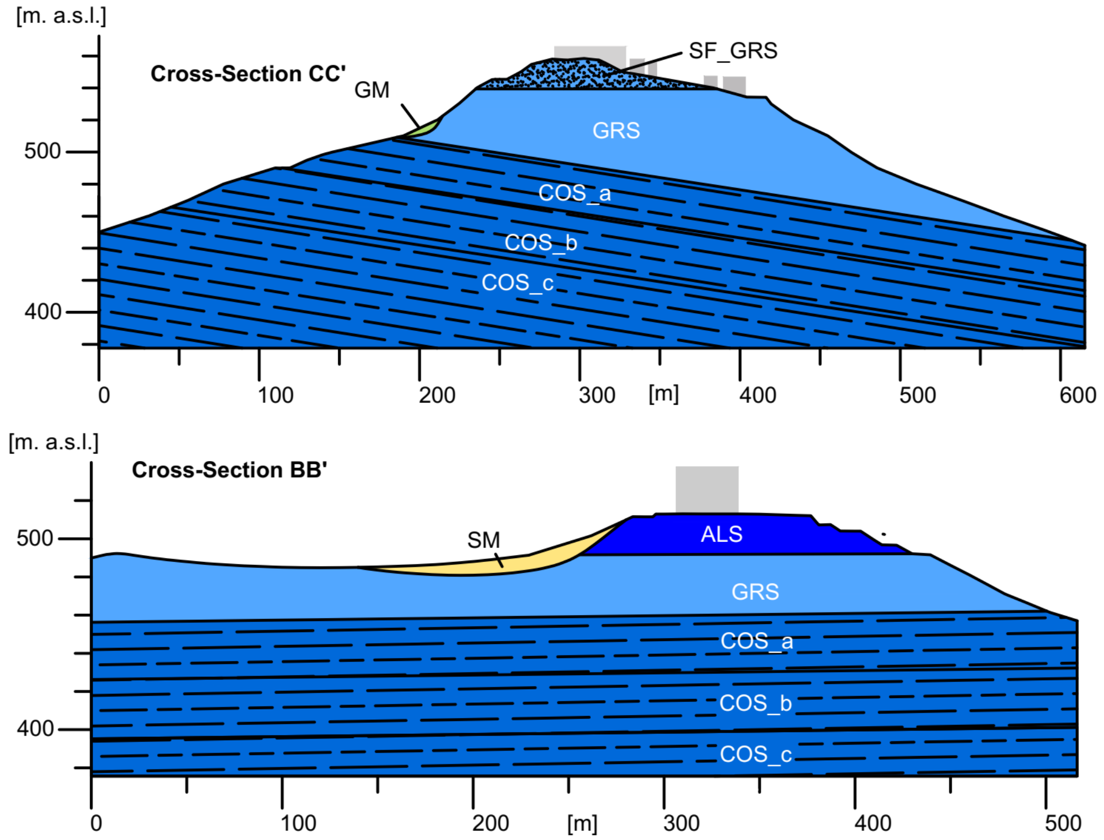
- Foti et al. 2018 Proc. XXV CGT, Torino
- Pagliaroli et al. 2019 Proc. 7th ICEGE, Rome

Site Response Analyses: ground model

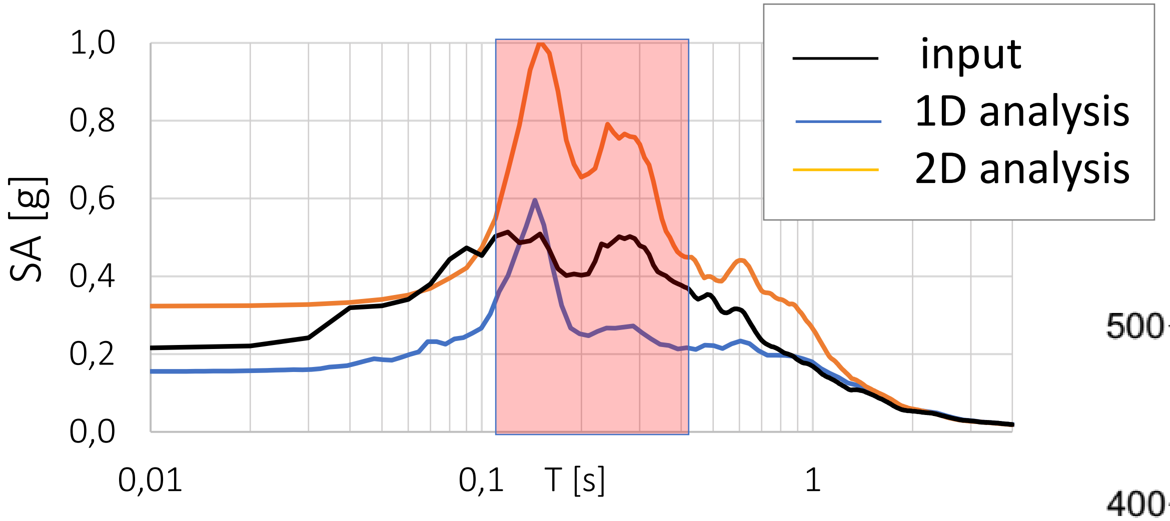
The topography of the site is characterized by a **NE-SW hilly ridge**. The historical center lies mainly on a cemented granular material from weathered (**SF_GRS**) to unweathered (**GRS**) bedrock, and on an alternation of stratified lithotypes (**ALS**).

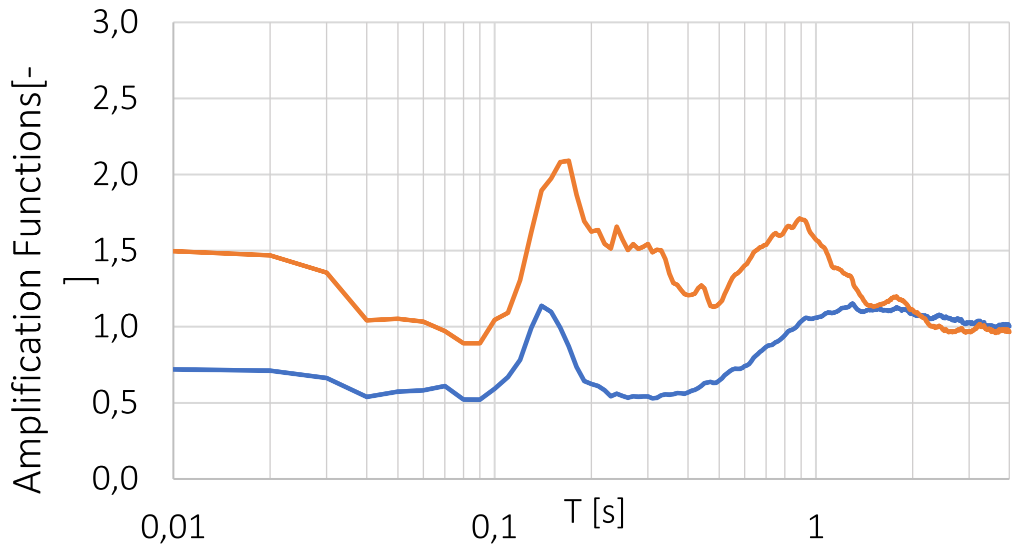
The deepest portion is constituted by the Blue Clays Formation (**COS**). On the sides of the ridge, there are 3-15 m thick coverings, classifiable as gravels and sandy gravels (**GM**) and sands and silty sands (**SM**).



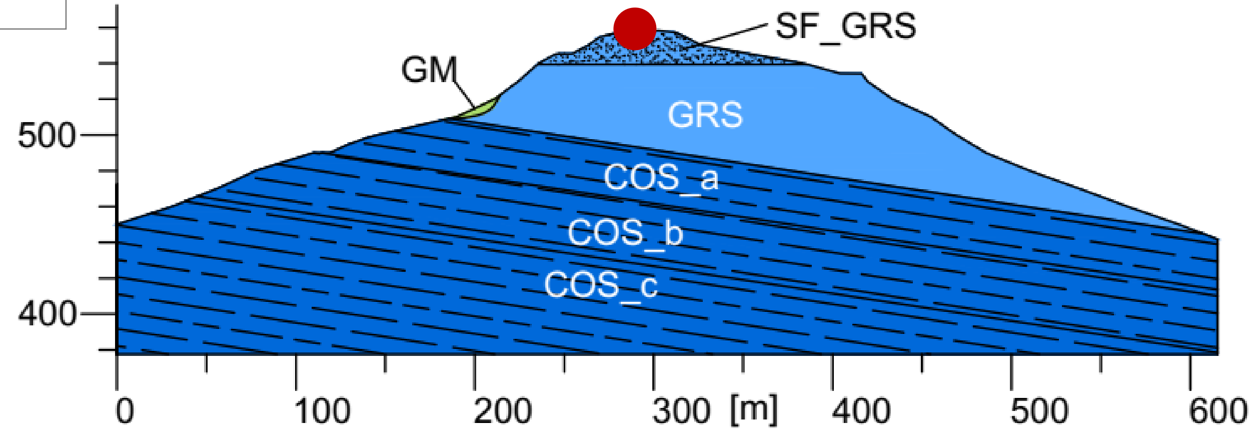


2D vs 1D Site Response Analyses





Cross-section CC'



- ✓ Relevance of the COS layer (softer than GRS)
  → **deep seismic bedrock**
- ✓ Marked **2D** effects
- ✓ Relevant **NL** effects for the top sediments

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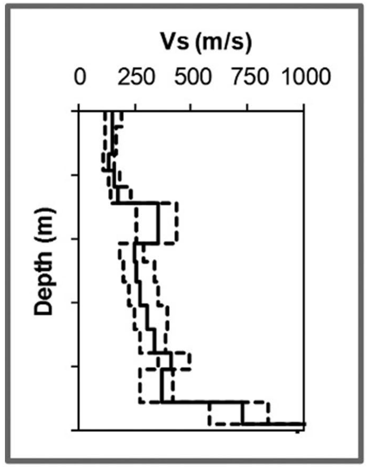
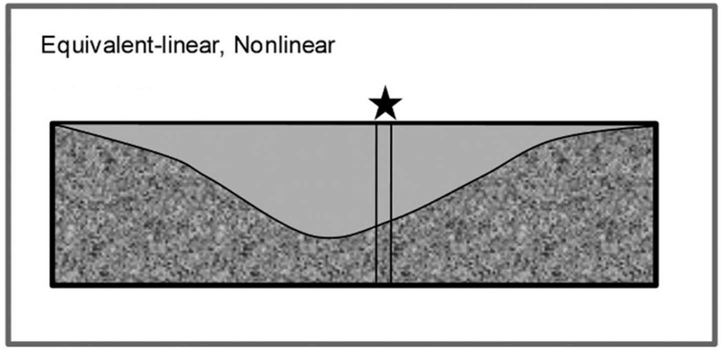
Uncertainties in Seismic Site Response analyses

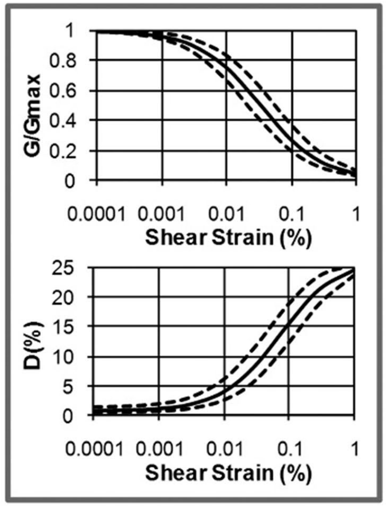
SHEAR WAVE VELOCITY PROFILE

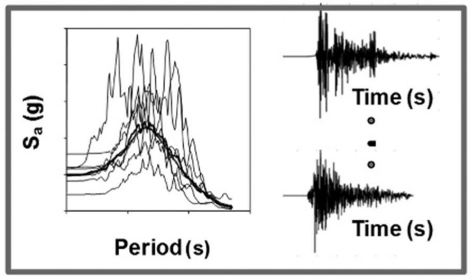


NONLINEAR APPROACH

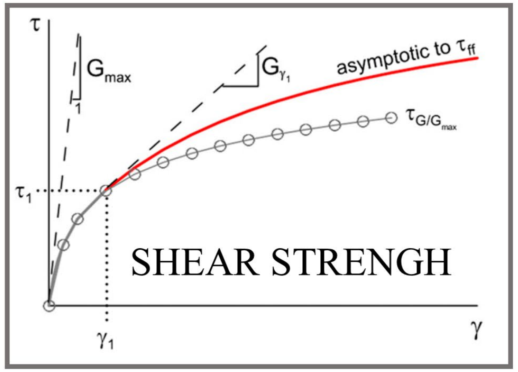


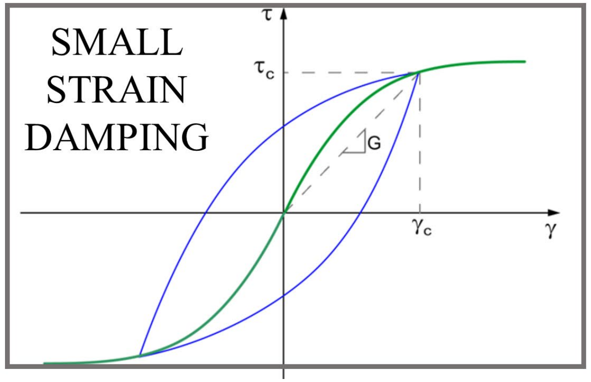
MRD CURVES





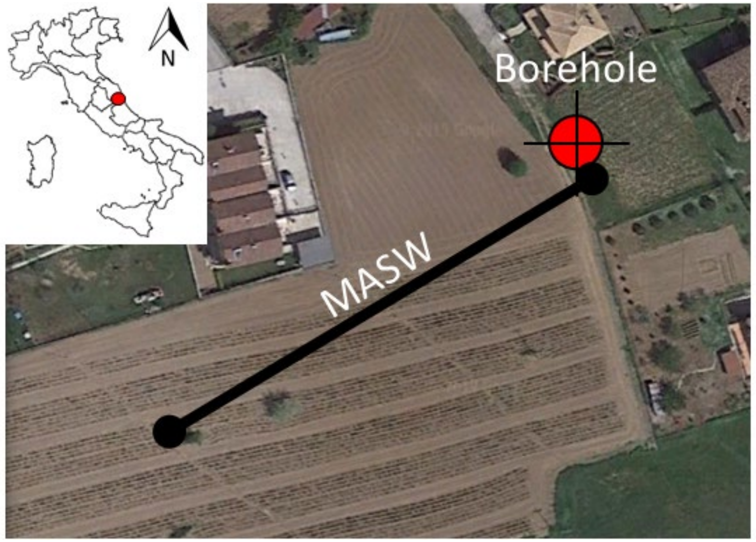
INPUT MOTIONS SELECTION



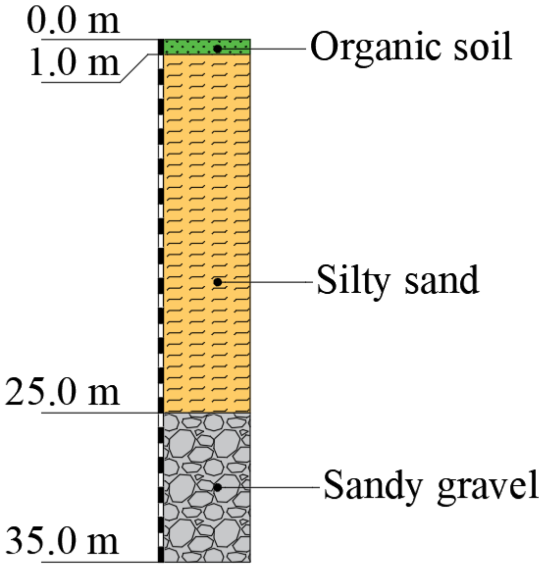


The Roccafluvione site

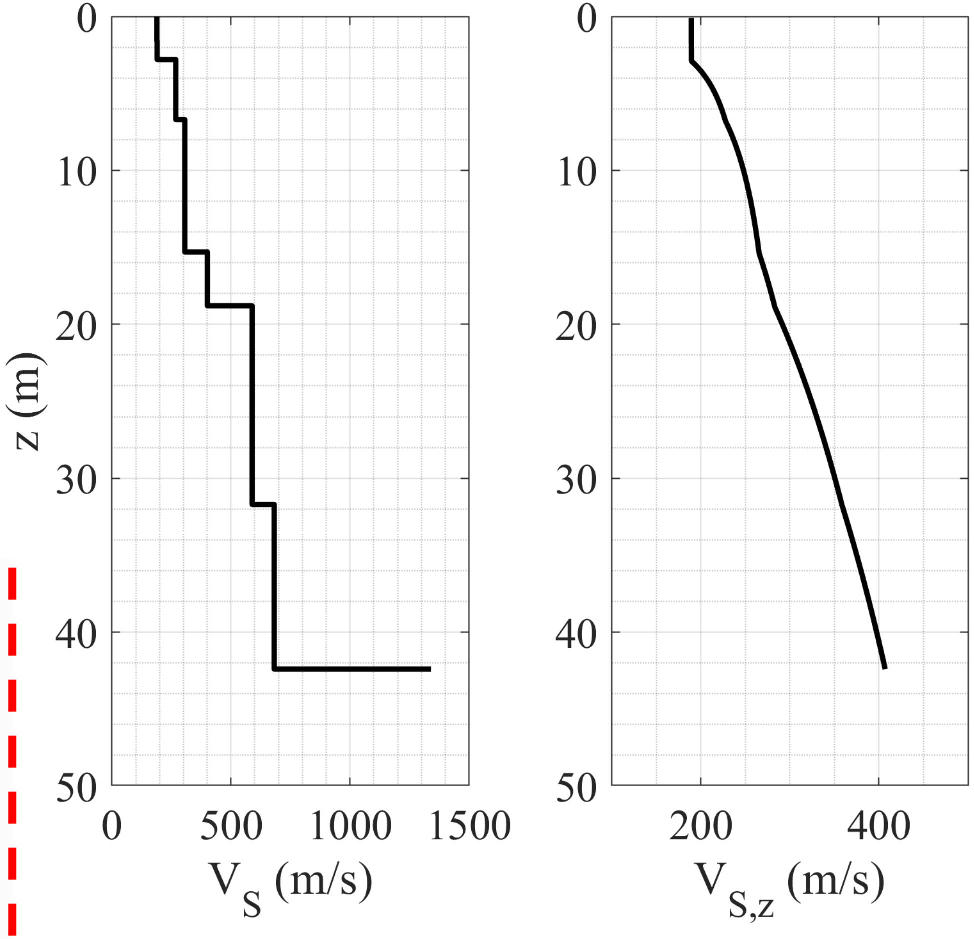
MASW and DHT tests were performed to get the Vs model
(Complete results are reported in the paper in the proceedings)



Borehole



MASW results



Guidelines for the good practice of surface wave analysis: a product of the InterPACIFIC project

Bulletin of Earthq. Eng. BEE 2018

Open Access

Sebastiano Foti[1] · Fabrice Hollender[2] · Flora Garofalo[1] · Dario Albarello[3] · Michael Asten[4] · Pierre-Yves Bard[5] · Cesare Comina[6] · Cécile Cornou[5] · Brady Cox[7] · Giuseppe Di Giulio[8] · Thomas Forbriger[9] · Koichi Hayashi[10] · Enrico Lunedei[3] · Antony Martin[11] · Diego Mercerat[12] · Matthias Ohrnberger[13] · Valerio Poggi[14] · Florence Renalier[15] · Deborah Sicilia[16] · Valentina Socco[1]

The Roccafluvione site

This case study shows the effect of uncertainties on the site response, with focus on the role of site characterization (V_S profile from field tests and MRD curves from the lab)

- **Ground models**: statistical sample of 1,000 ground models, with V_S profile randomized according to the geostatistical model implemented in Passeri (2019) and MRD curves from the model by Ciancimino et al. (2019);
- **Input motions**: collection of 7 acceleration time histories, compatible with the seismological features of the Roccafluvione site;
- **Type of analysis**: Equivalent Linear (EQL) approach, with the DEEPSOIL software;

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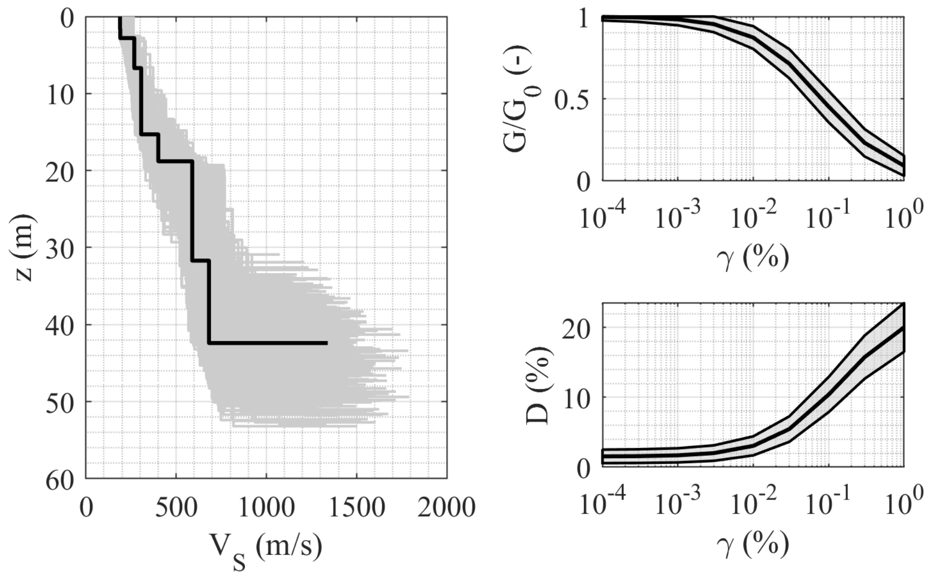

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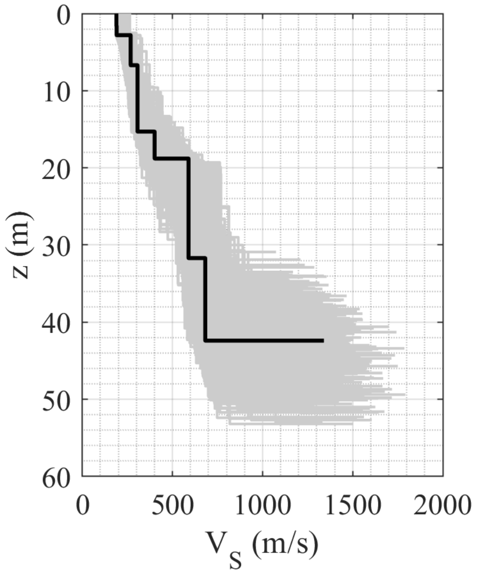

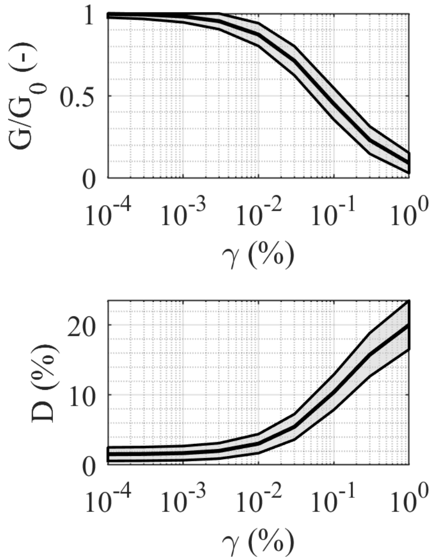

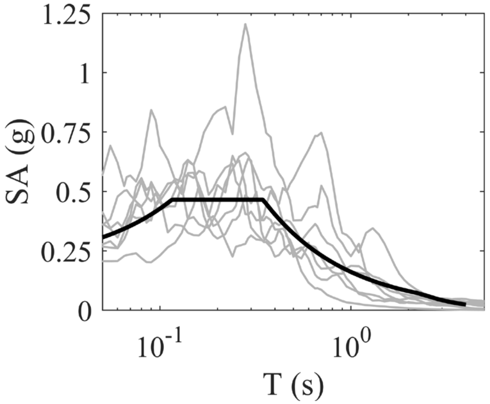

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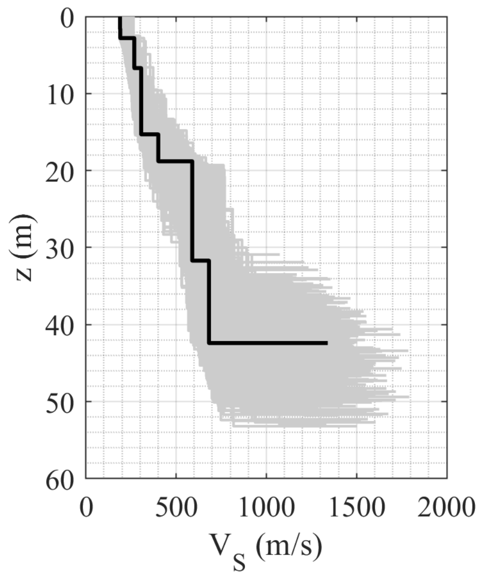

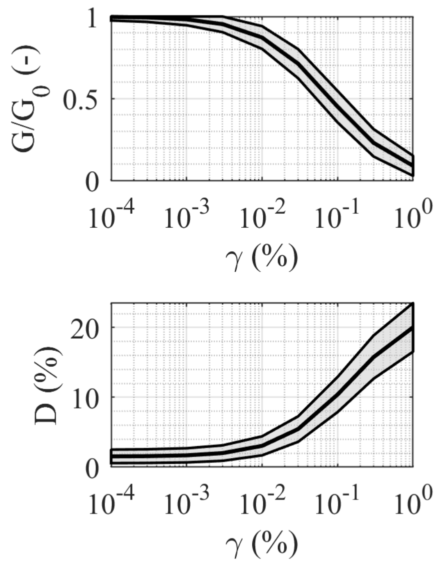

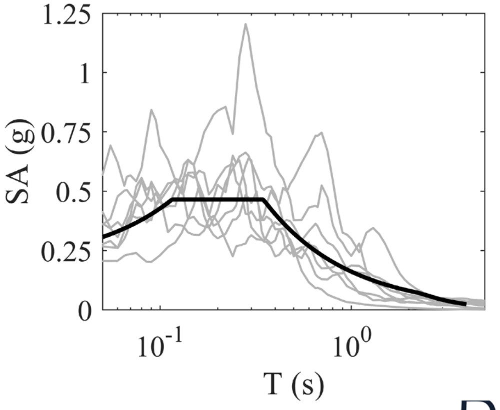

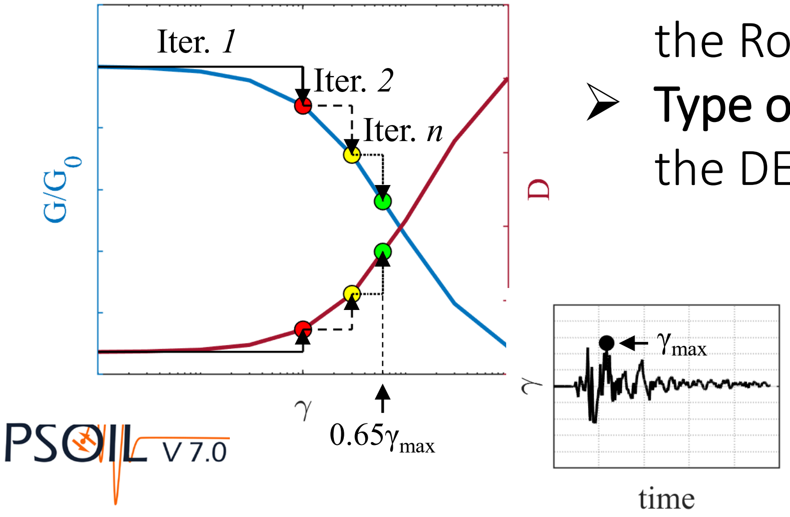

DEEPSOIL V 7.0

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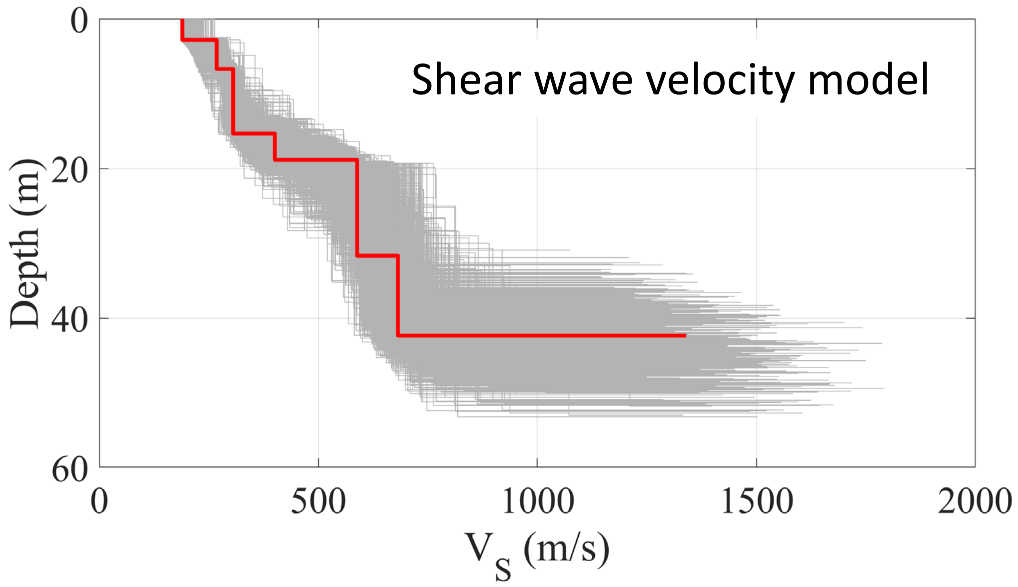
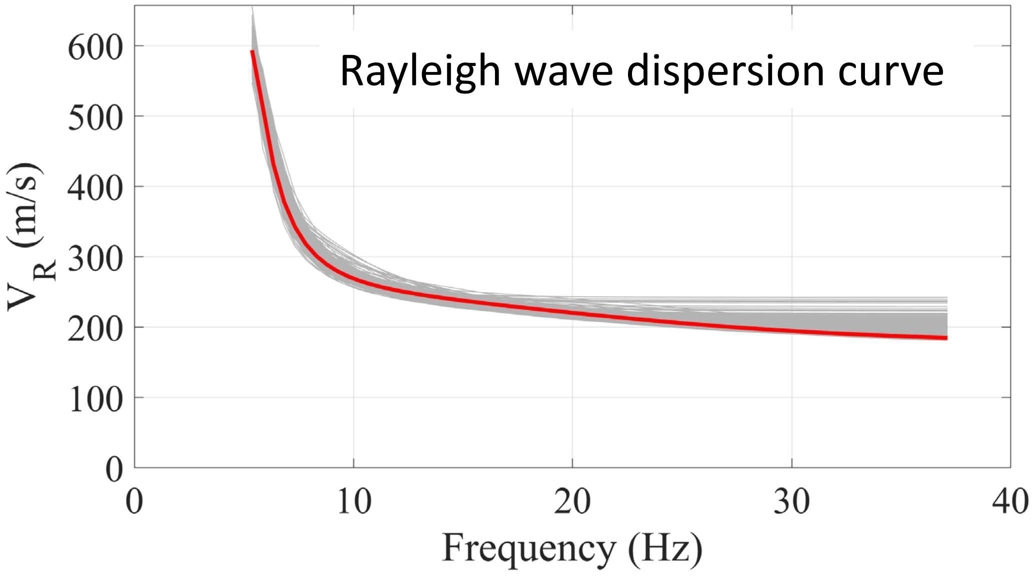
- **Type of analysis**: Equivalent Linear (EQL) approach, with the DEEPSOIL software;

Shear wave velocity profile





A new geostatistical model for the management of uncertainties in shear wave velocity profiles

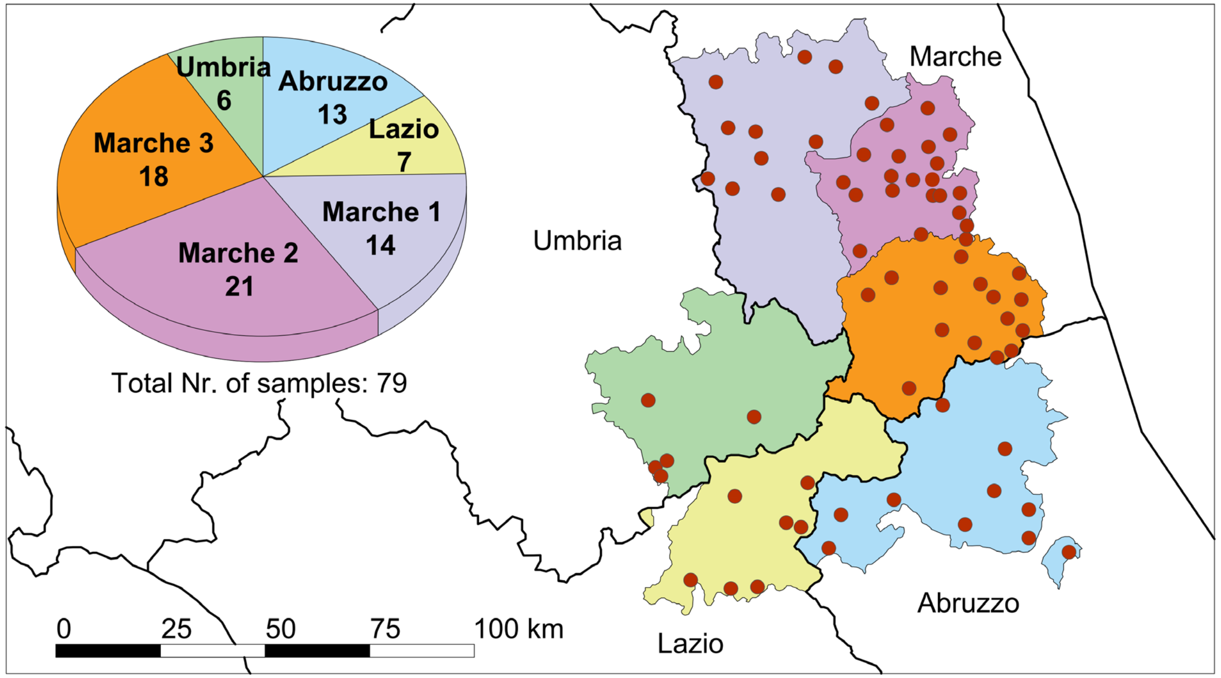
Passeri, Foti, Rodriguez-Marek – submitted to SDEE

- The proposed geostatistical model assumes **a separation between the fundamental quantities of space and time**, which in turns avoid the generation of parasitic (i.e., multiple) uncertainties → avoid the generation of “unrealistic” models
- It has been **calibrated** with a high-quality database of surface wave experimental measurements which was specifically compiled (Passeri et al., submitted to BEE)
- The model is **flexible** as it is based on a global architecture that can be adapted to other seismic tests (e.g., Down-Hole tests).

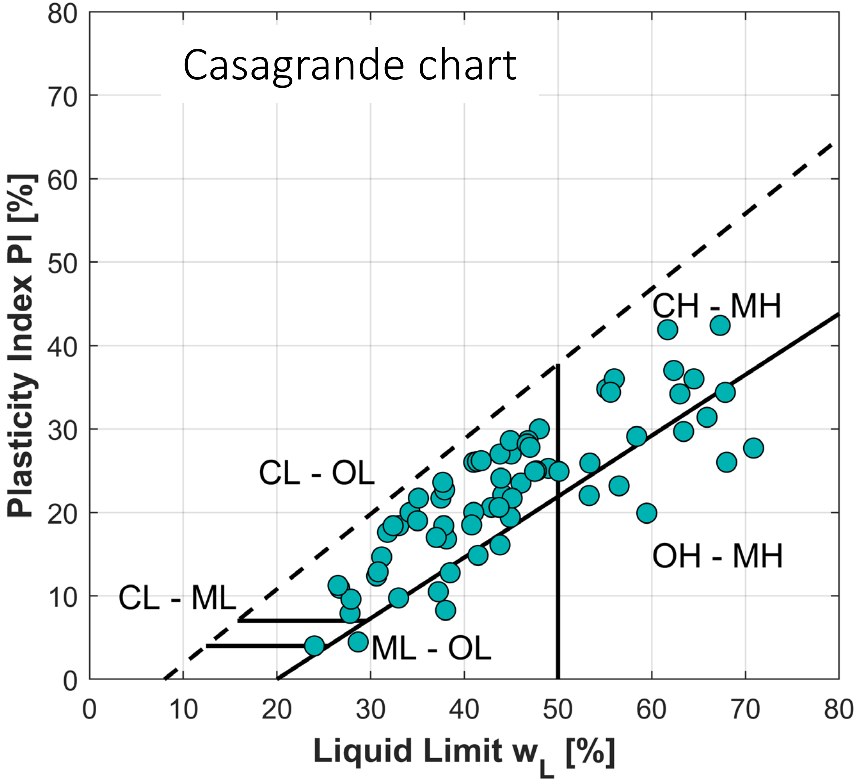
THE MODEL OVERCOMES THE DRAWBACKS OF THE USUAL METHODS ADOPTED FOR TECHNICAL AND SCIENTIFIC APPLICATIONS AND DESCRIBED IN EPRI (2013).

Modulus Reduction & Damping Curves

- The model proposed by **Ciancimino et al. (2019)** is adopted to describe the MRD curves. It is a **specialized version of the Darendeli (2001) model**, adapted to **capture the specific behavior soils from the Central Italy area**.
- The study was developed within the framework of the SM studies carried out after the Central Italy seismic sequence, several universities were then involved in the project.
- The database includes information from **79 cyclic tests** carried out on clays and silts of low plasticity with PI ranging from 0 to 45% representative of the soils in the region

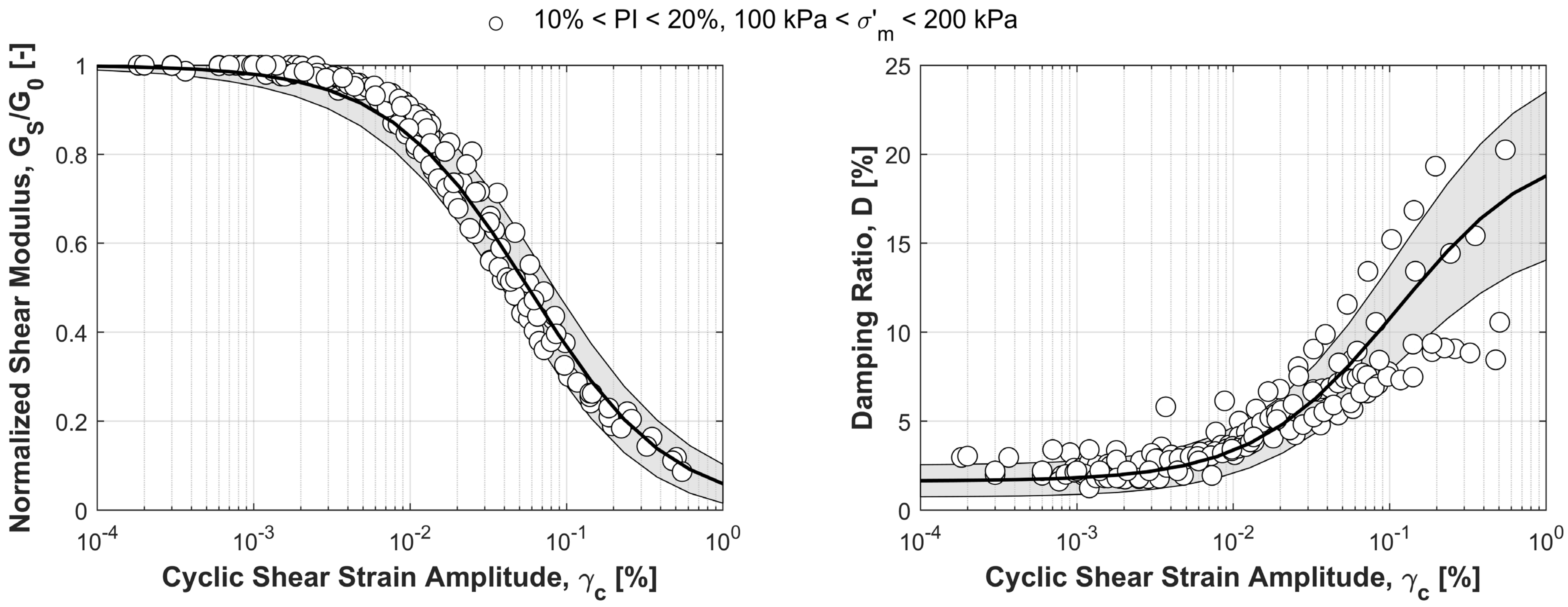


Locations of the investigated sites



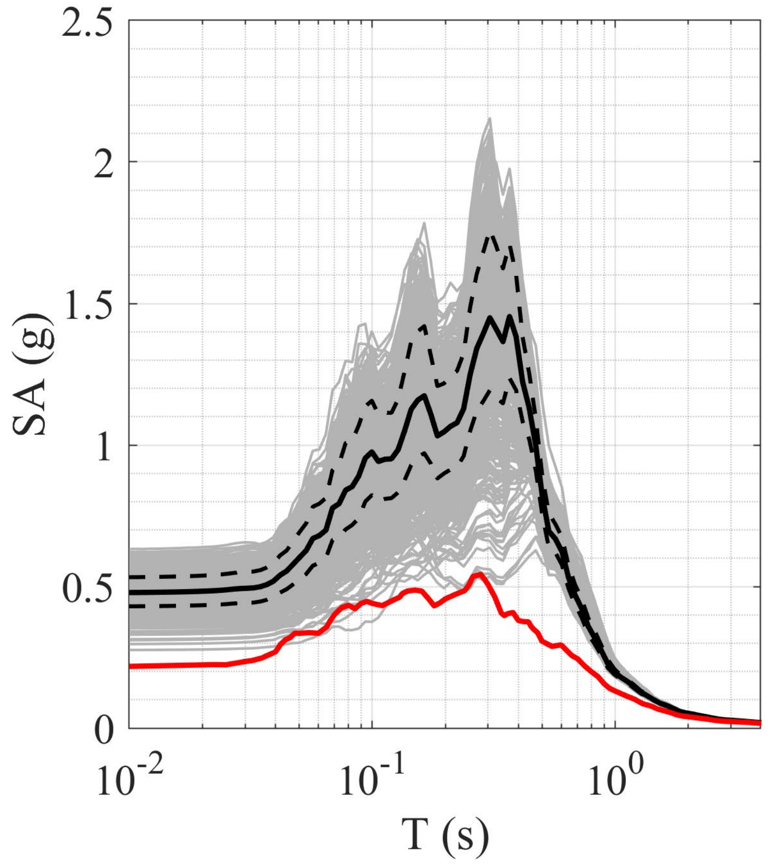
Modulus Reduction & Damping Curves

- **MR curves** described through a **modified version of the hyperbolic model** proposed by Stokoe et al. (1999), as a function of **PI and σ'_m**
- **Small-strain damping ratio** modelled taking into account separately the influence of **PI, σ'_m, and f**
- **D curves** modelled assuming the **Masing (1926) criteria** and fitting the experimental data through an **adjusting function**
- It provides information on the **statistical dispersion** of the results, which can be used to quantify the **uncertainty affecting the MRD curves**.

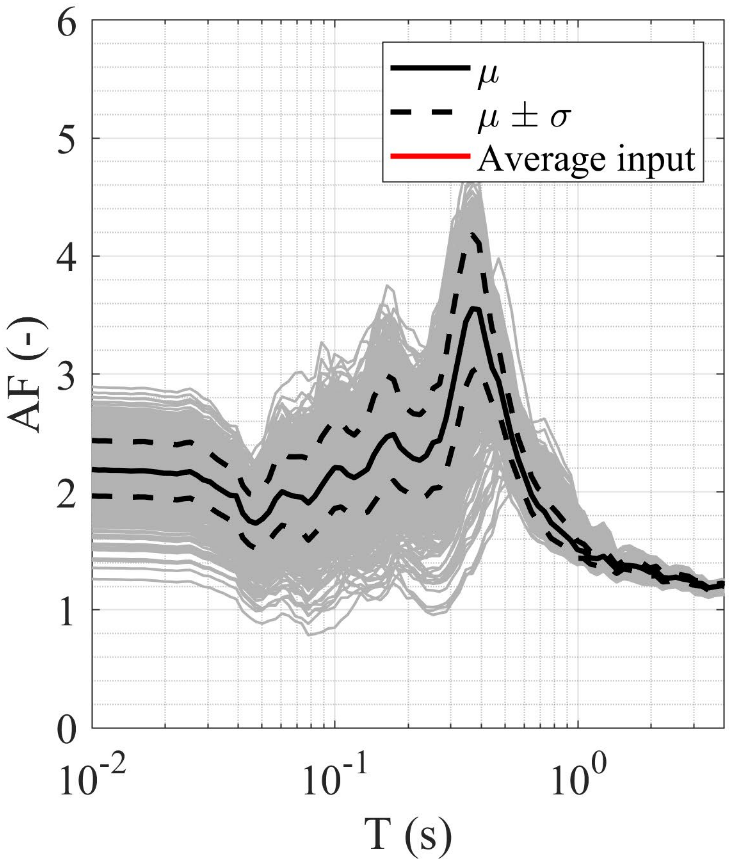


Results: Acceleration Spectra

The soil model exhibits an amplification of the ground motion at all vibration periods, with a peak at 0.25 s



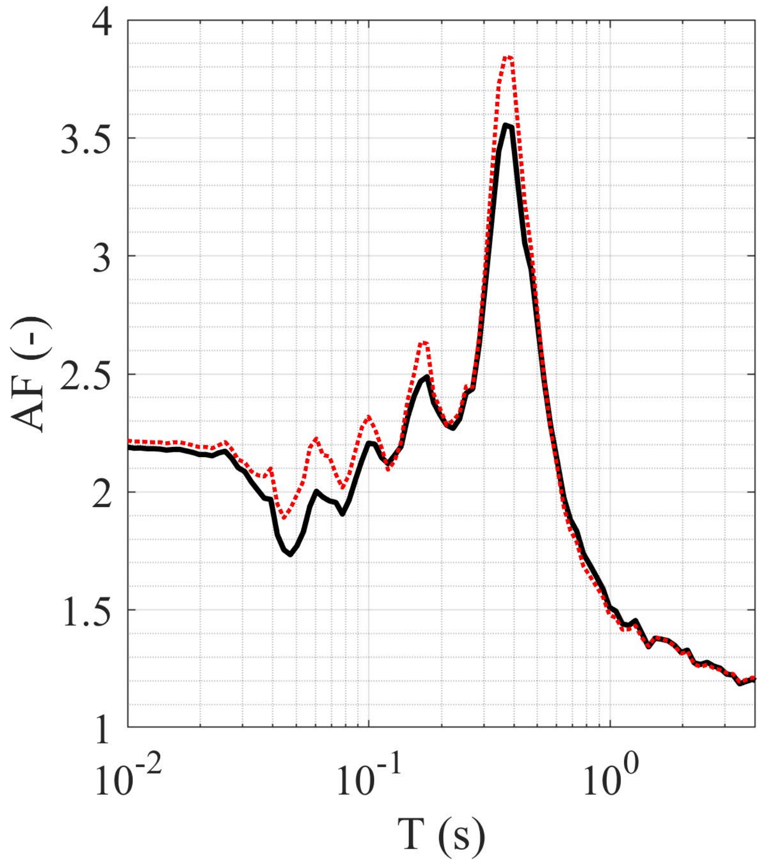
Elastic response spectra



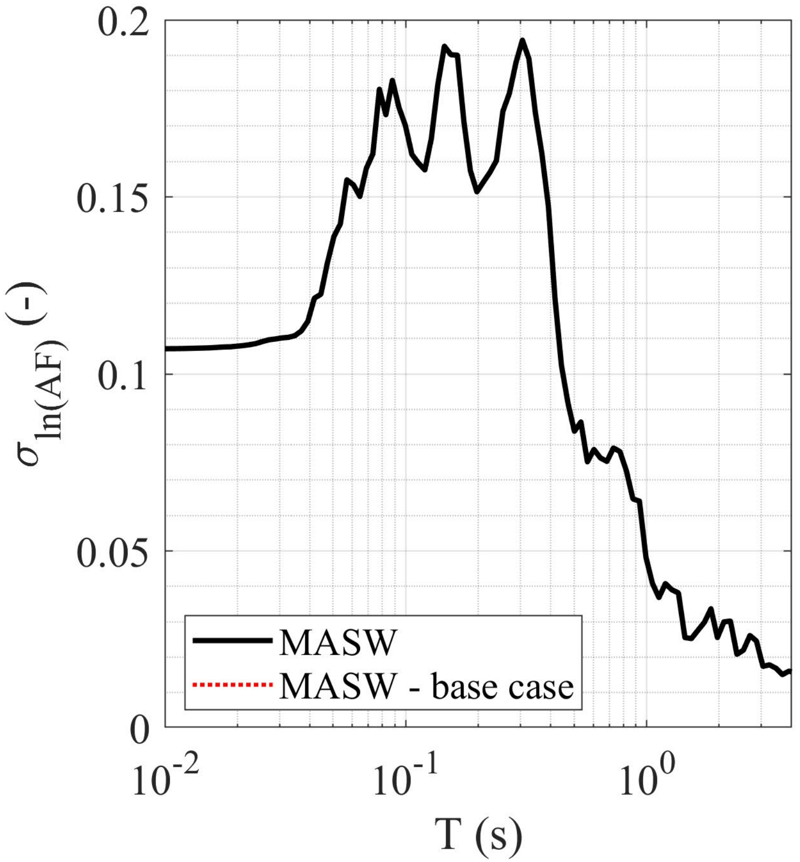
Amplification functions

Results: Amplification Function

- **Mean amplification**: the mean amplification ranges between 1.7 and 2.5 at small vibration periods, increasing up to 3.5 at 0.25 s. Moreover, the result is consistent with the analysis performed on the original Vs profile ("**base-case**")
- **Standard deviation**: the standard deviation of the amplification function is close to 0.1 at short vibration periods and assume a value of 0.2 in the range 0.08-0.2 s



Mean amplification function



Standard deviation of the amplification function

Final remarks

- Seismic Microzonation and Single Site Seismic Response are complementary tools that provide different degrees of details for seismic design (and urban planning).
- Identification, quantification and management of uncertainties is of primary importance in any (geotechnical) engineering application, especially when dealing with (dynamic) non-linear problems where an a-priori choice of conservative values of the parameters is not possible
- Geostatistical methods are useful to manage uncertainties, but it is of foremost importance that unrealistic models are avoided (i.e. the models have to comply with experimental evidence): overestimation of the variability may lead to unconservative results
- Urging need for standard of executions and guidelines for dynamic testing of soils and rock and for geophysical methods to improve the quality of the results and to promote the adequate use of these tools (→ ISO)
- Eurocode 7 – part 2 Ground Investigations will include a new clause "Mechanical response to cyclic and dynamic loads and parameters for seismic design"

THANK YOU FOR YOUR KIND ATTENTION!

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