II LEVEL SEISMIC MICROZONATION AND ABACUSES OF SEISMIC AMPLIFICATION

REGIONE DEL VENETO

1222·2022 800 ANNI

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LESSON CONTENTS

- Seismic Risk in Italy

- Seismic Microzonation

- Abacuses of Amplification Factors (F.A.):

  Step 1: Model of the subsoil and seismic input

  Step 2: Seismic Site Simulations

  Step 3: Abacuses' realization

SEISMIC RISK IN ITALY

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Basilic of San Francesco d’Assisi with
Cimabue Paintings (XIII Century)
Central Italy Seismic Sequence (1997)

Student House
L’Aquila Earthquake (2009)

Hotel Roma
Amatrice Earthquake (2016)

SEISMIC RISK IN ITALY

SEISMIC RISK: ???

SEISMIC RISK IN ITALY

SEISMIC RISK: Hazard * Vulnerability * Exposed Value

SEISMIC RISK IN ITALY

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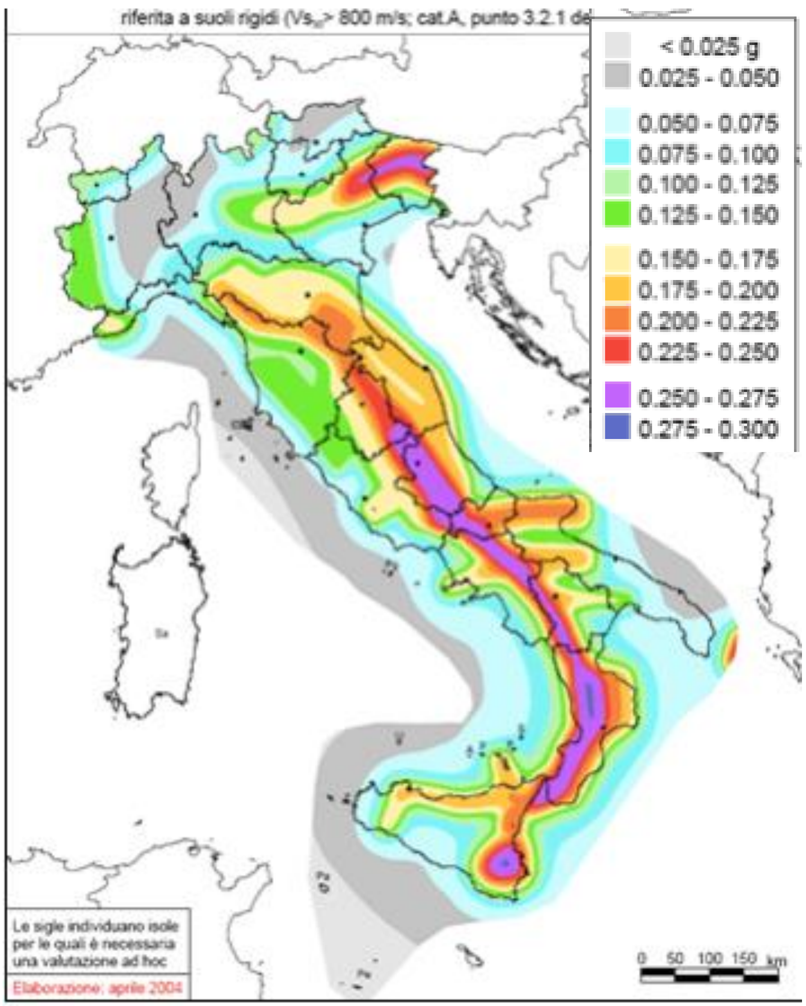
Basilic of S. Francesco d'Assisi with Cimabue Paintings
Central Italy Seismic Sequence (1997)

Student House
L'Aquila Earthquake (2009)

Italy is one of the country in the Mediterranean with the highest seismic risk

SEISMIC RISK IN ITALY

SEISMIC HAZARD MAP



Seismic hazard maps provide **probabilistic** estimates of the earthquake ground shaking exceeding a given threshold in a given geographic region within a given time window.

Provides the 10% probability of exceedance in 50 years of the horizontal acceleration at rock sites (i.e., soil category A, V_{s30} > 800 m/s, Nuove Norme Tecniche per le Costruzioni, NTC 2008.)

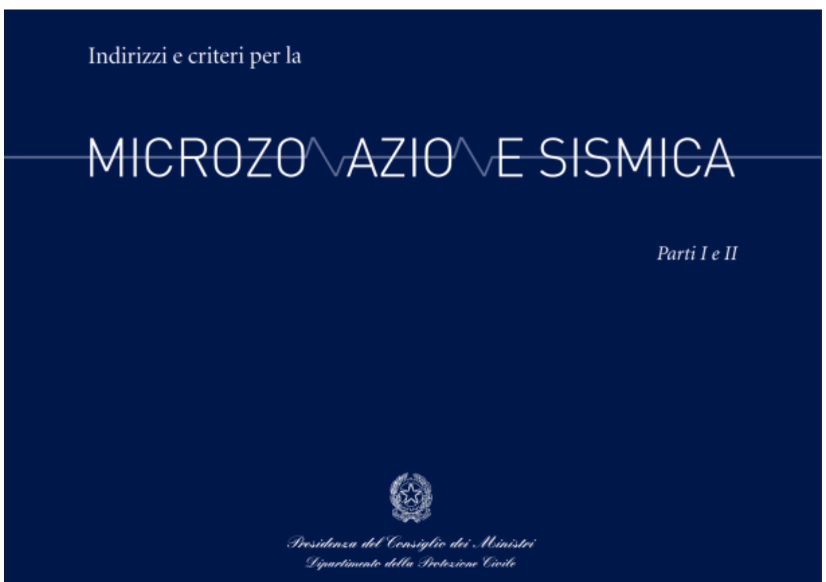
The engineering bedrock →v_s≥ 800 m/s (soil category A = stiff soil or rock).
Softer soils →v_s≤ 800 m/s
Are expected to amplify the seismic action

SEISMIC REGULATION

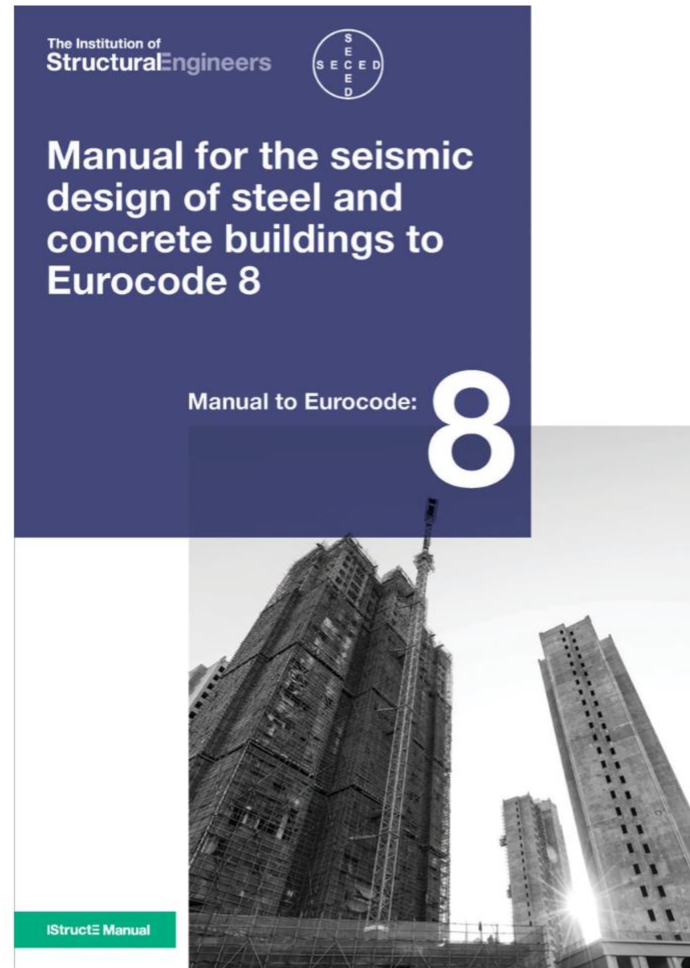
BUILDING SEISMIC SAFETY COUNCIL

of the National Institute of Building Sciences

Program on Improved Seismic Safety Provisions



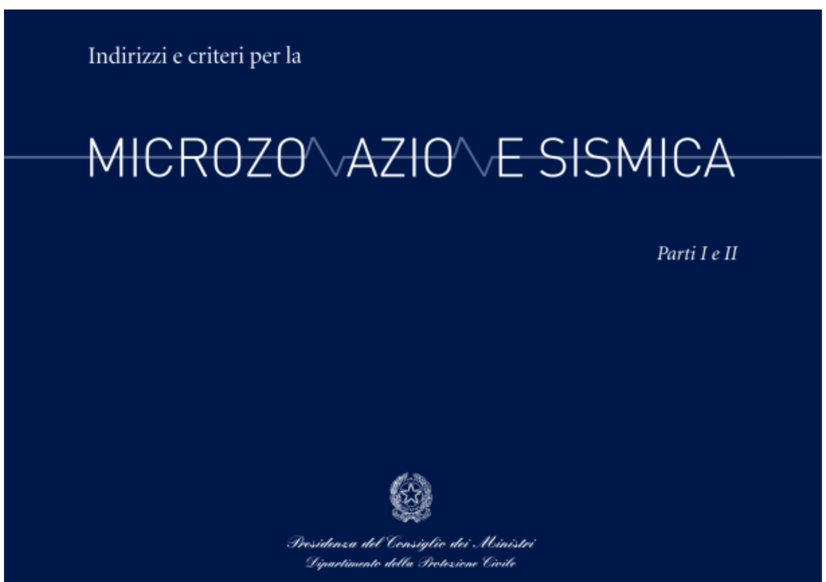
In Italy ICMS



SEISMIC REGULATION

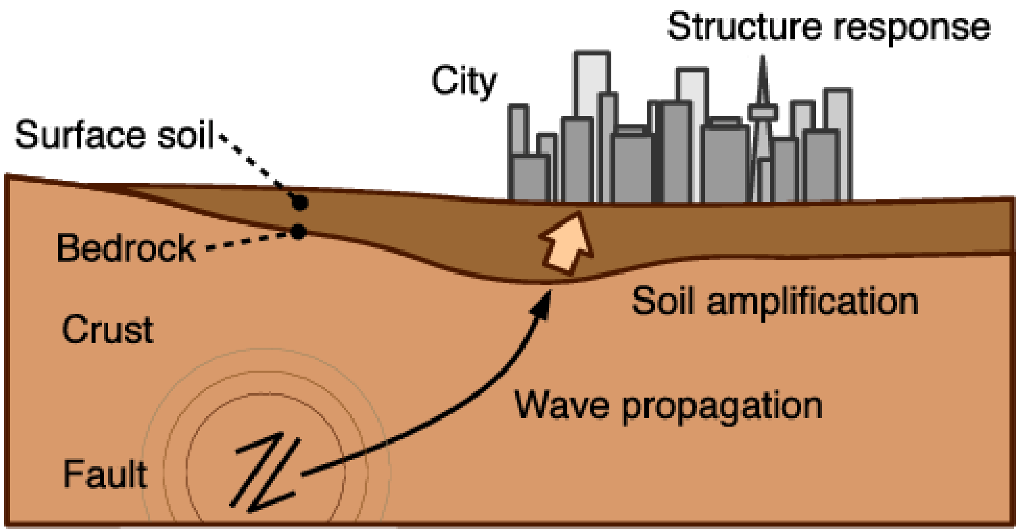
Guideline to perform studies of the dynamic behaviour of the soils.

Useful for application in urban planning and engineering design.



In Italy
ICMS

SEISMIC LOCAL RESPONSE



1) When an earthquake occurs, the seismic waves generated by the fault propagate through the crust.

2) The seismic waves are amplified near the interfeace of bedrock and soft sediment.

3) The building and structures are shaken by the resulting ground motion → site response

SEISMIC MICROZONATION

SEISMIC SITE RESPONSE

MICROZONATION LEVEL

- I LEVEL

- II LEVEL

- III LEVEL

SEISMIC MICROZONATION

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SEISMIC SITE RESPONSE

MICROZONATION LEVEL

- I LEVEL: it consists of a collection of existing data that are processed to divide the investigated area into **qualitatively** homogeneous Microzones. → Map of homogeneous zones.

- II LEVEL: **Quantitative elements** (e.g.amplification factors) associated with the homogeneous zones are introduced. → Map of seismic microzonation

- III LEVEL: it represents the level of maximum detail that should be applied. **Detailed Seismic Microzonation Map** covering particular issues or areas

SEISMIC SITE RESPONSE

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SEISMIC SITE RESPONSE

MICROZONATION LEVEL: AMPLIFICATION FACTORS' ABACUSES

CLAY

Vs30(m/s)	200	250	300
F.A. PGA	1.8	1.7	1.6
F.A. S1	1.5	1.4	1.4
F.A. S2	3.2	2.5	2.4
F.A. S3	3.8	3.8	3.6

SAND

Vs30(m/s)	250	300	350
F.A. PGA	1.5	1.4	1.2
F.A. S1	1.3	1.3	1.2
F.A. S2	2.1	2.1	1.8
F.A. S3	3.5	3.5	3.1

GRAVEL

Vs30(m/s)	400	450	500	550	600
F.A. PGA	1.3	1.2	1.2	1.2	1.2
F.A. S1	1.2	1.2	1.2	1.3	1.1
F.A. S2	1.8	1.8	1.7	1.8	1.6
F.A. S3	3.1	3.1	3.1	3.1	2.8

AMPLIFICATION FACTORS: easy and immediate parameters descibing the geo-lithological conditions

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SEISMIC SITE RESPONSE

MICROZONATION LEVEL: AMPLIFICATION FACTORS' ABACUSES

FINAL SCOPE: URBAN PLANNING

⬇

SEMPLIFIED APPROACH FOR THE AMPLIFICATION ESTIMATES

For local engineering projects (building design or building renovation) the III level is needed.

II LEVEL MICROZONATION

ICMS: Specific regional microzonation analysis (local geological features)

VENETO REGION

Collaboration Agreement Between Regione Veneto and University of Padua

REGIONE DEL VENETO

SEISMIC MICROZONATION

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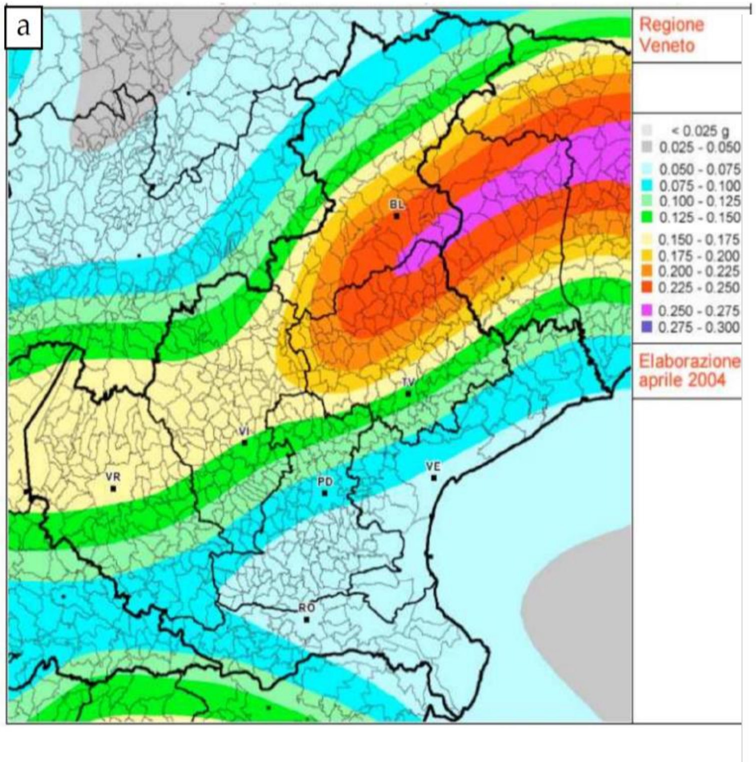
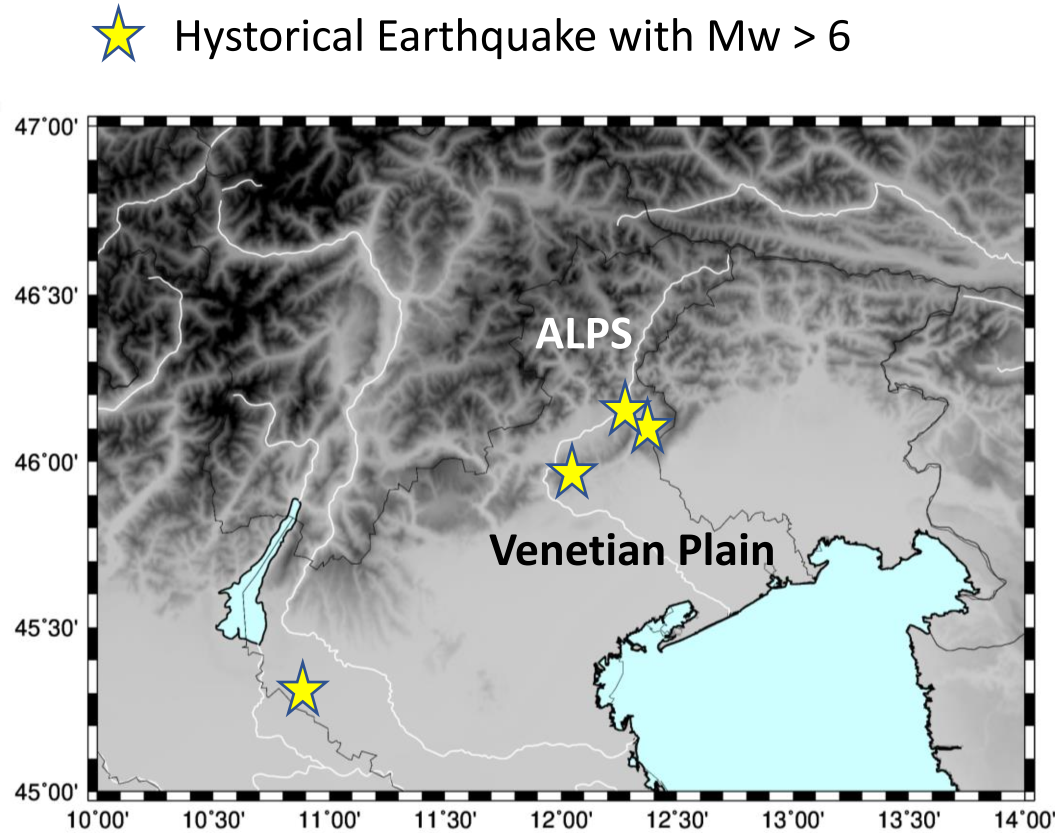
VENETO REGION



Mid-to-high seismic active area



Large and Deep alluvial basin

SEISMIC MICROZONATION

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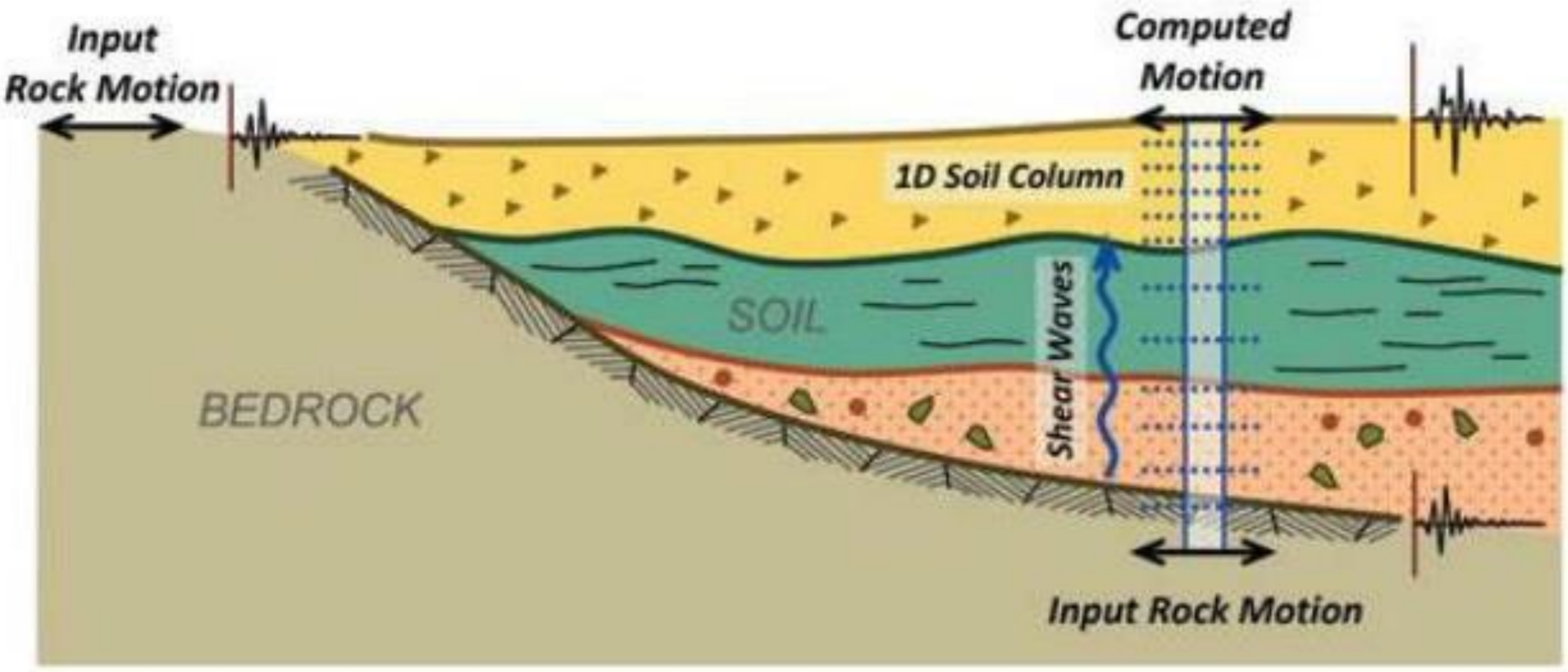
VENETO REGION

With simple methods we quantify the amplification phenomena



ABACUSES

STEP 1

- 1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS
- 1.2 GEOPHYSICAL PARAMETERS OF THE UNITS
- 1.3 SEISMIC INPUT SELECTION

STEP 2

- 2.1 STRATA SOFTWARE
- 2.2 AMPLIFICATION FACTOR ESTIMATIONS
- 2.2 RANDOM GENERATION OF Vs PROFILES

STEP 3

- 3.1 ABACUSES REALIZATION

ABACUSES: STEP 1

1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS

Subdivide the Veneto region in macro-areas, with dominant geological formations and same seismic behaviour.

Available data:

- Detailed Maps of different soil types
- Geotechnical official documents provided by Regione Veneto
- Other geophysical surveys performed by Geoscience Department, University of Padova

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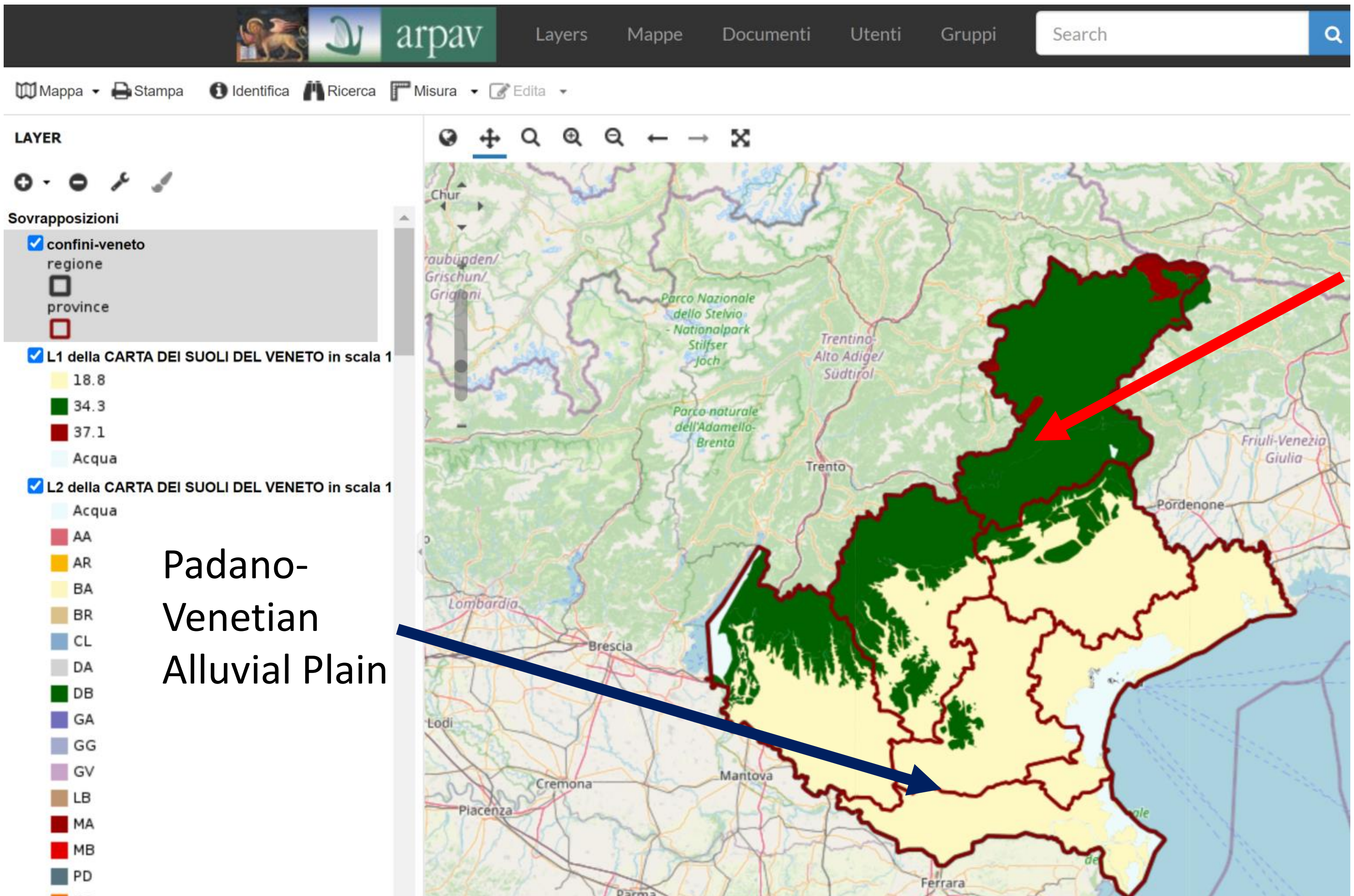
1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS



Padano-Venetian Alluvial Plain

Calcareous and Dolomitic Formation (Jurassic/ Cretaceous)

ABACUSES: STEP 1

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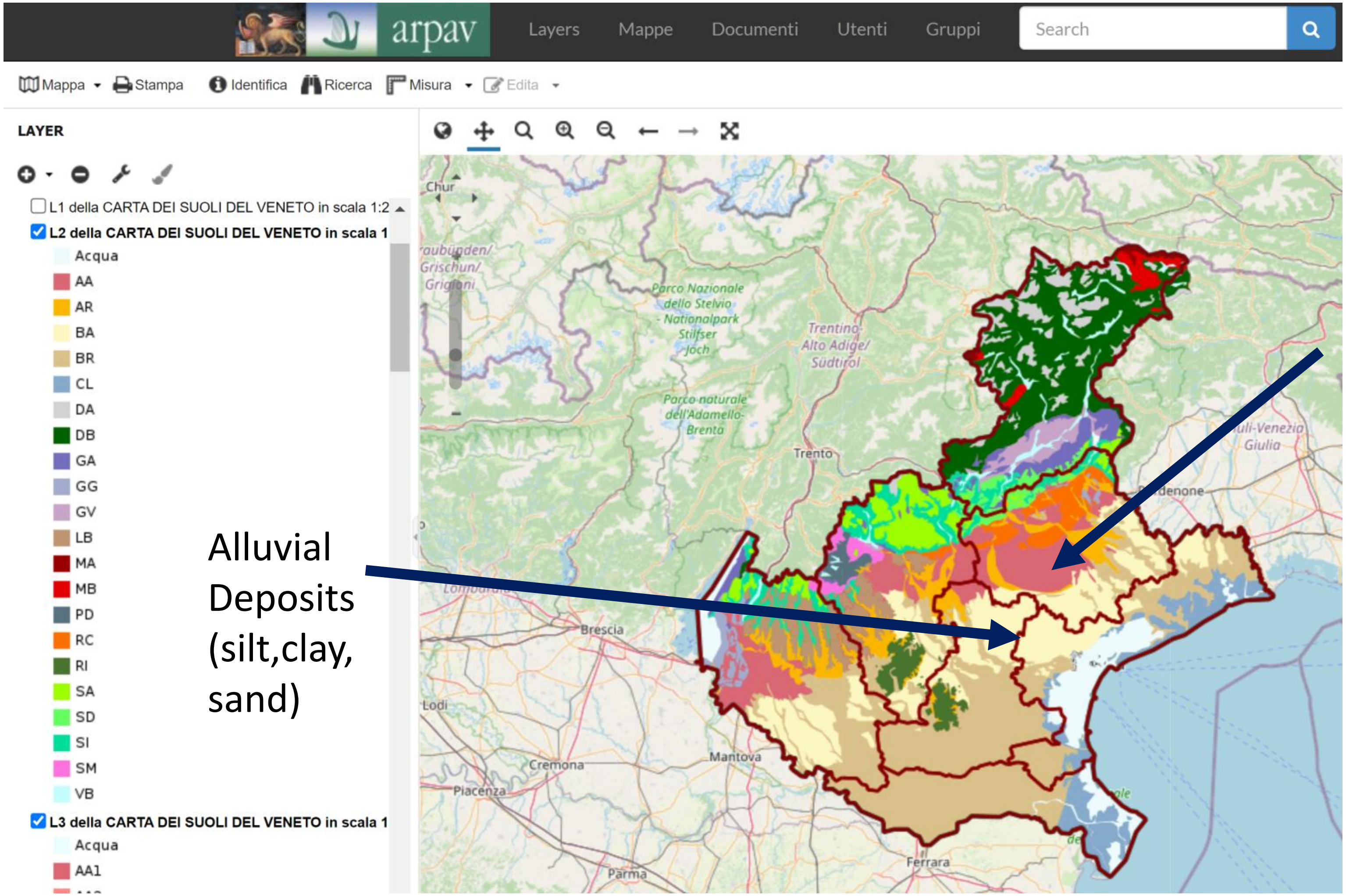
1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS



Alluvial Deposits (silt,clay, sand)

Gravelly Fluvio-glacial deposits Conoids

ABACUSES: STEP 1

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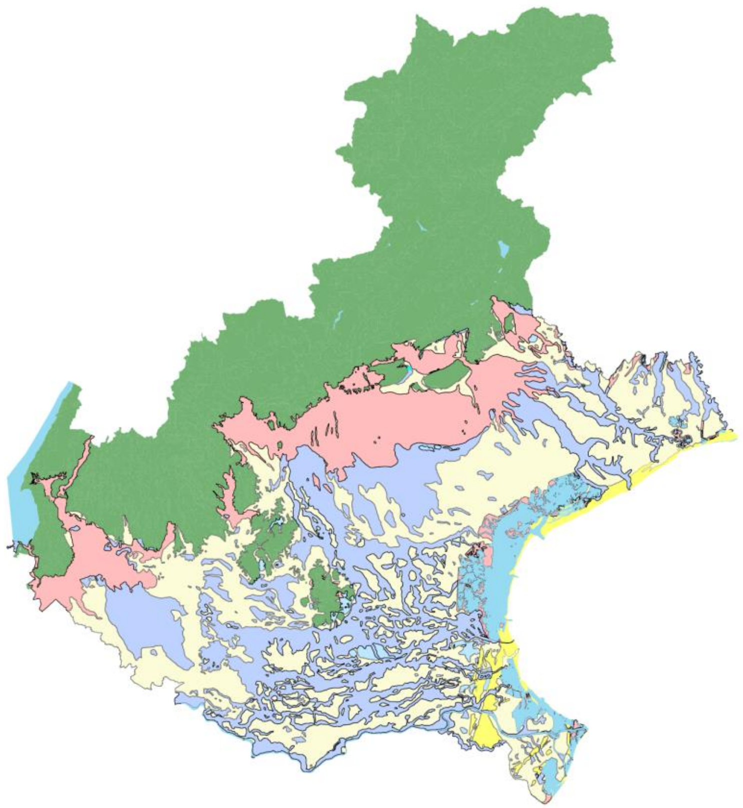
1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS

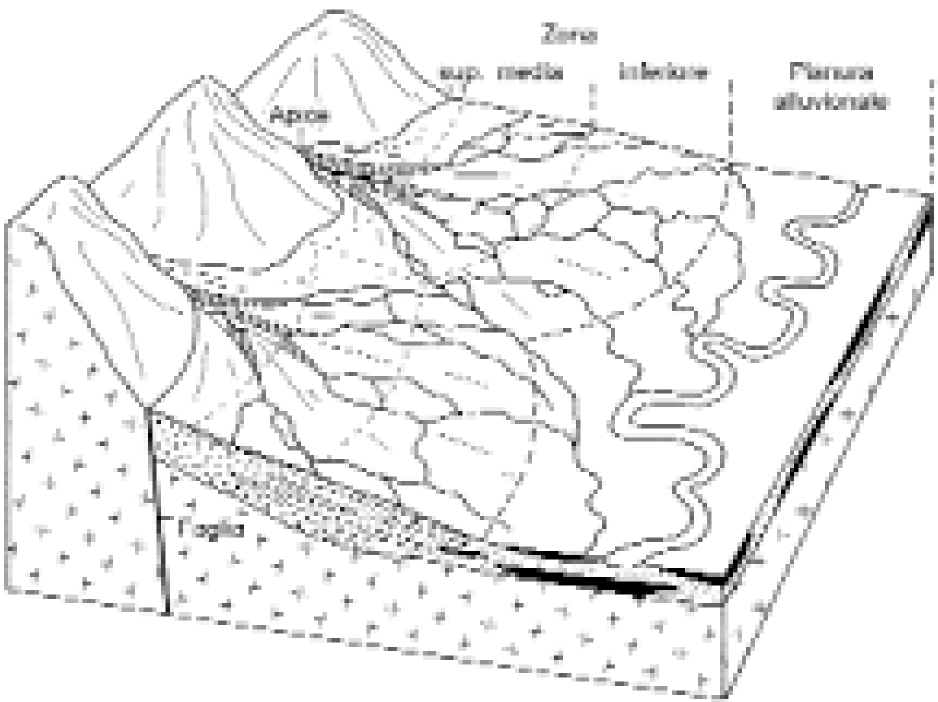
FINAL RESULT

LITHO-STRATIGRAPHIC UNITS or MACRO-ZONES:

- **GRAVEL**
- **SAND**
- **CLAY**
- **MOUNTAIN (ALPINE AND PRE-ALPINE DEPOSITS)**



1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS



CLAY SAND GRAVEL

- GRAVEL
- SAND
- CLAY
- MOUNTAIN (ALPINE AND PRE-ALPINE DEPOSITS)

ABACUSES: STEP 1

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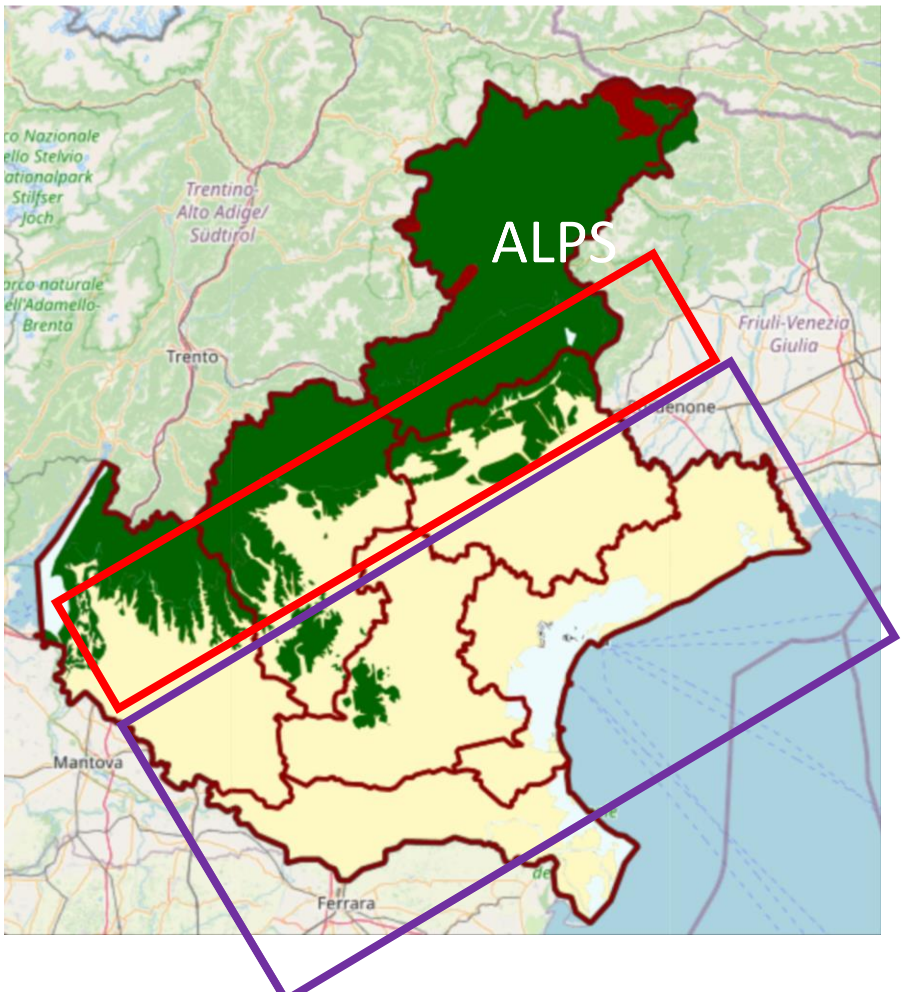
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS



Pre-Alpine zone (variable thickness)

Alluvial Plain zone (thickness greater than 30 meters)

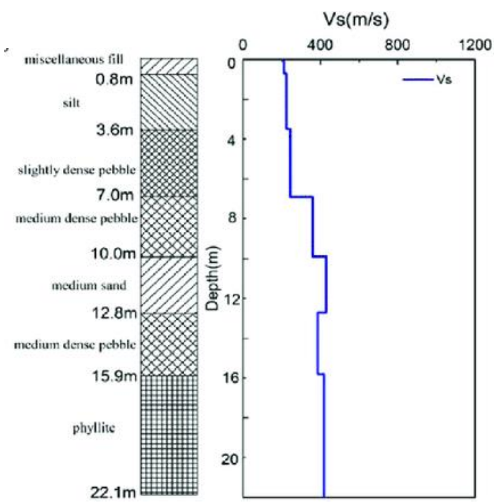
ABACUSES: STEP 1

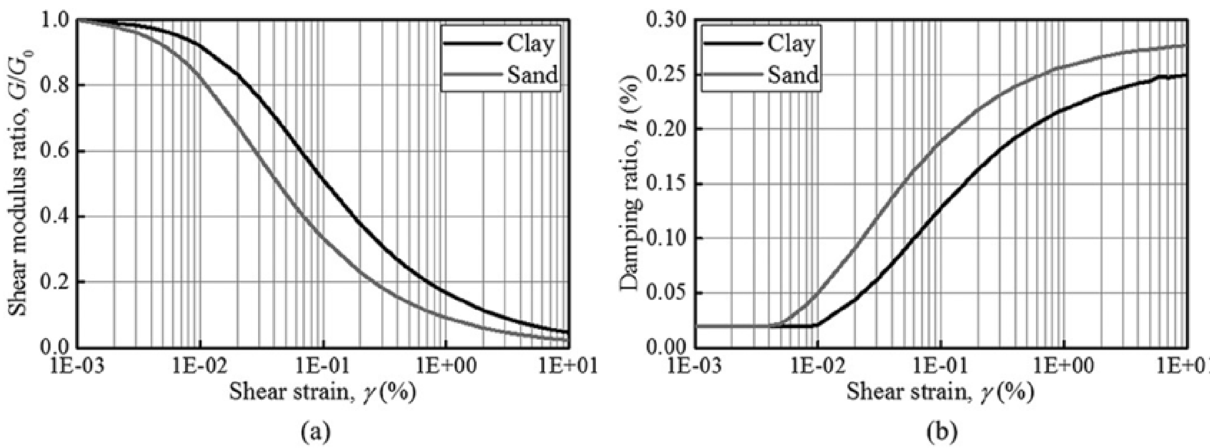
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

Geophysical Parameters (useful for II level microzonation analysis):

- Shear-waves velocity profiles

- Non-linear curves (Damping ratio and shear-modulus reduction)

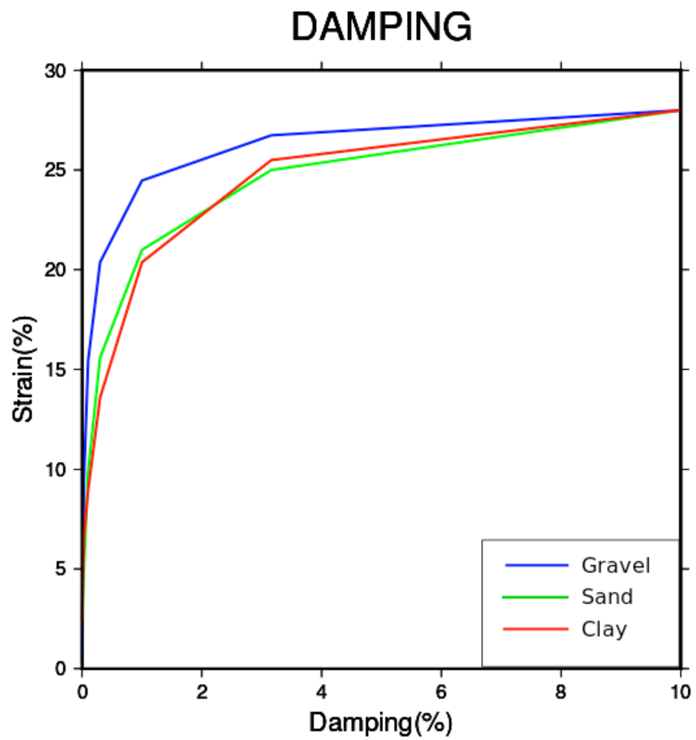


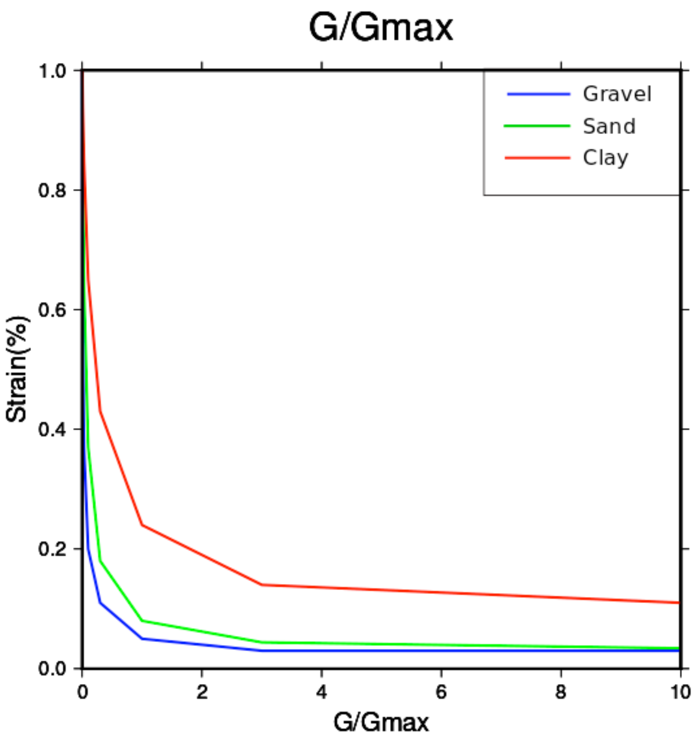


ABACUSES: STEP 1

1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

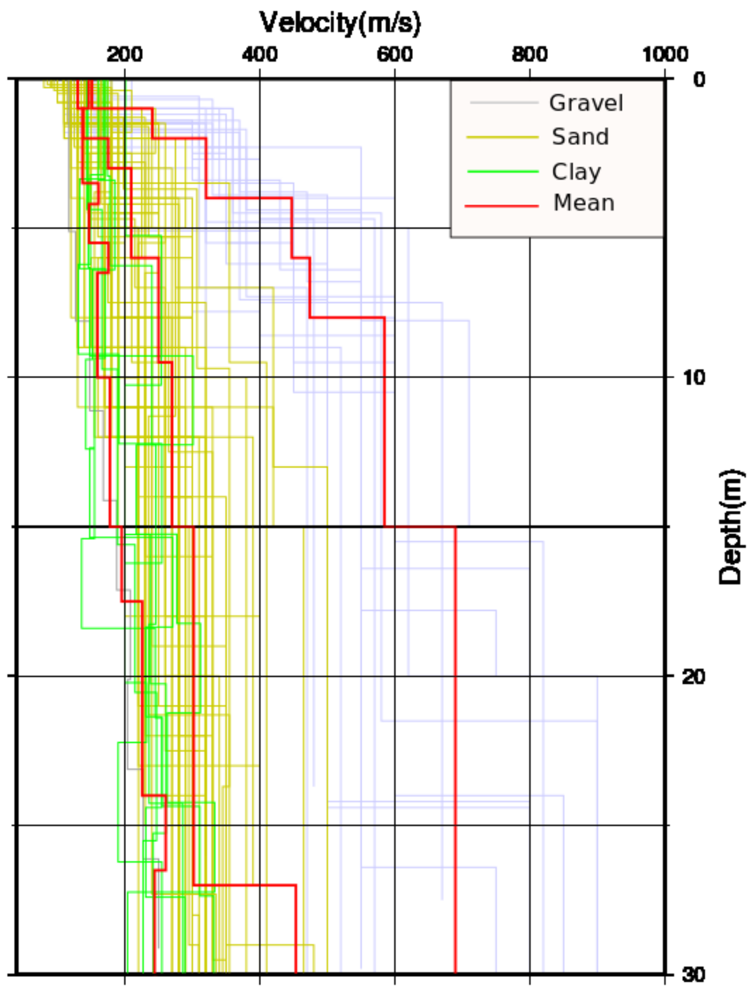
- Non-linear curves: Reference model in literature (Idriss and Sun, 1990)





ABACUSES: STEP 1

1.2 GEOPHYSICAL PARAMETERS OF THE UNITS



- Shear-waves velocity profiles: collect geophysical data contained in geological technical evaluation documents.

- Selection of high-quality data

- Average
- Standard Deviation

ABACUSES: STEP 1

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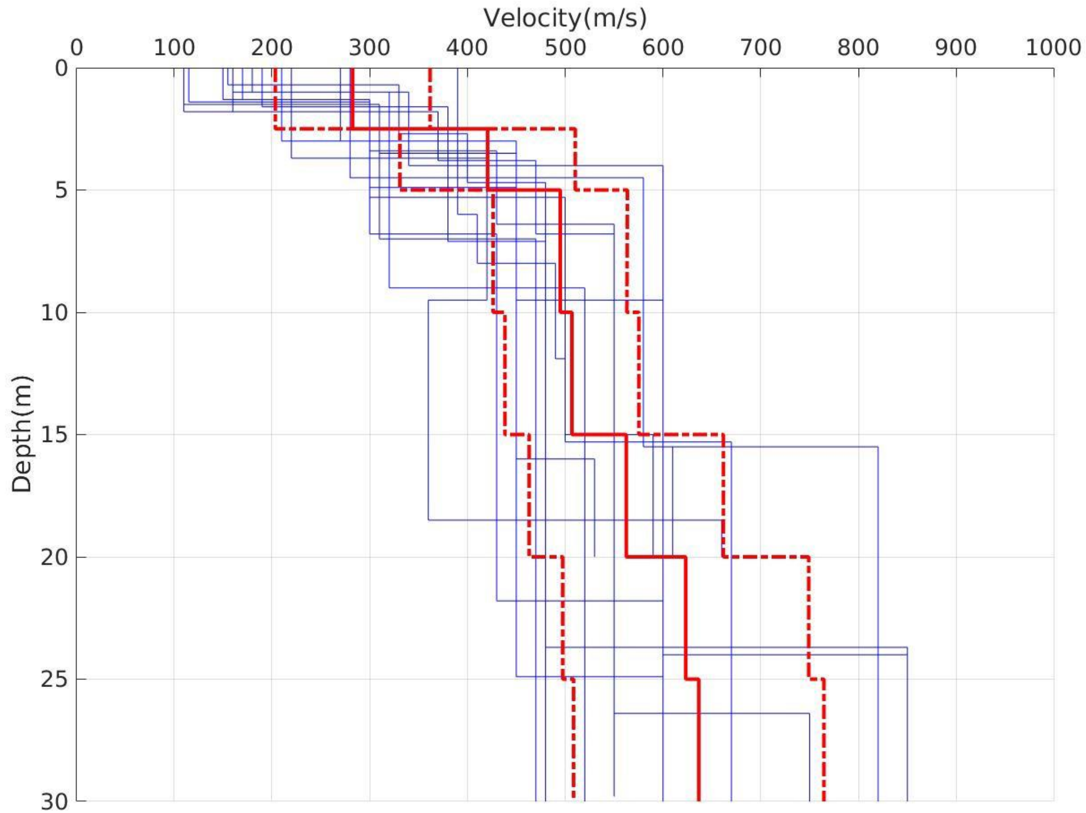
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

MAXIMUM DEPTH = 30 meters

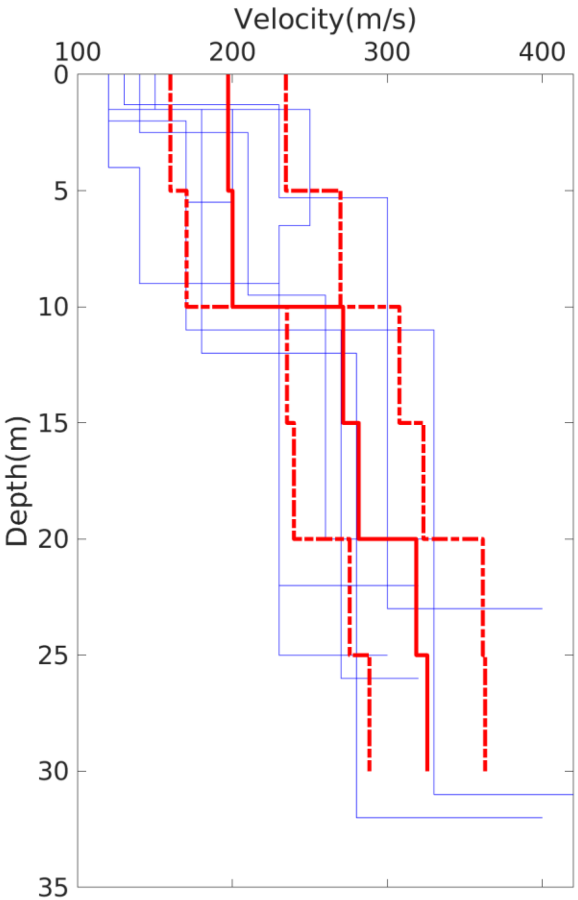
GRAVEL



ABACUSES: STEP 1

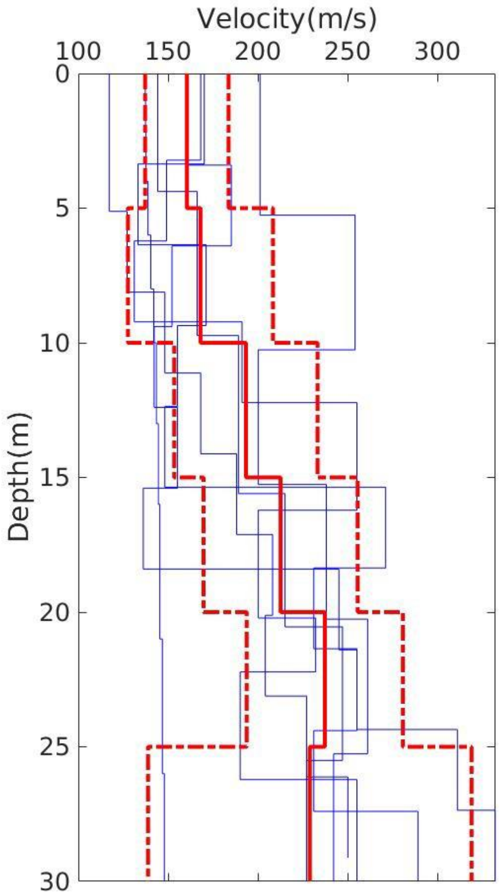
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

SAND



MAXIMUM DEPTH = 30 meters

CLAY

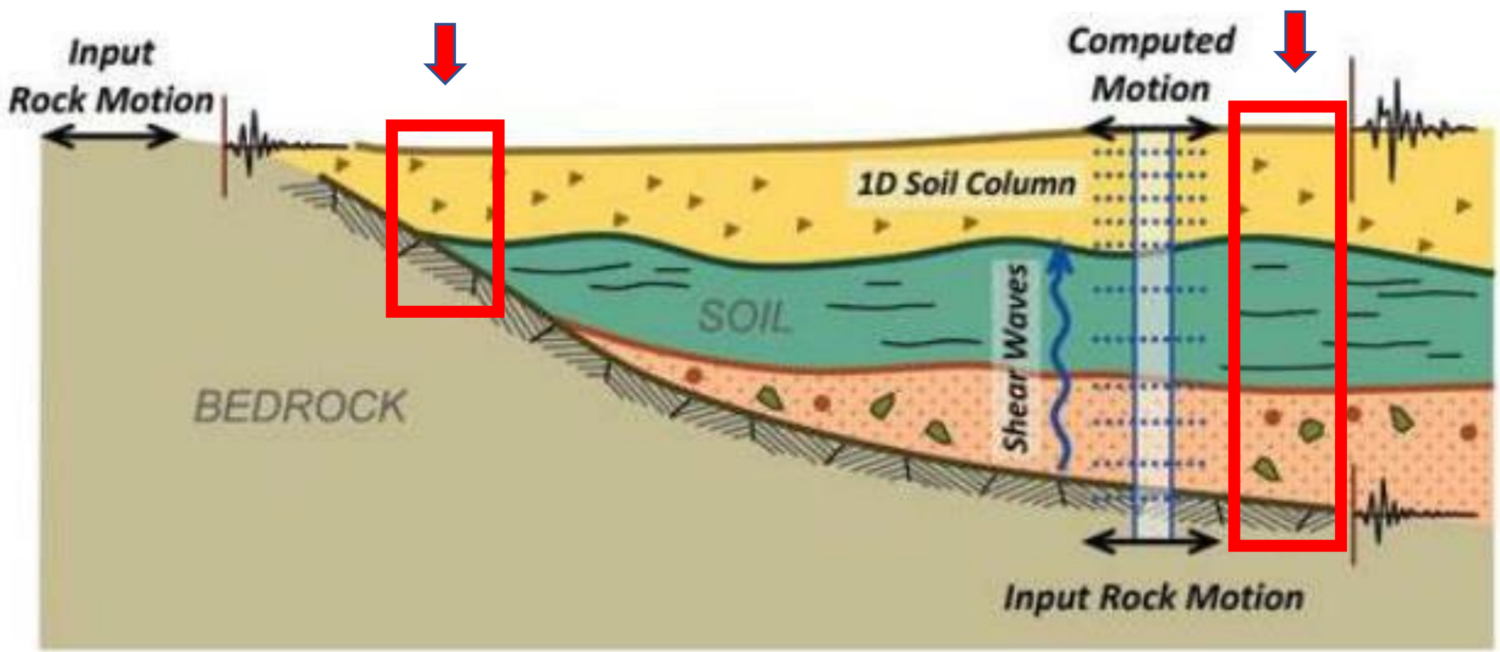


ABACUSES: STEP 1

1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

Shallow Vs profiles (30 meters)

Deeper vs structures ???????



ABACUSES: STEP 1

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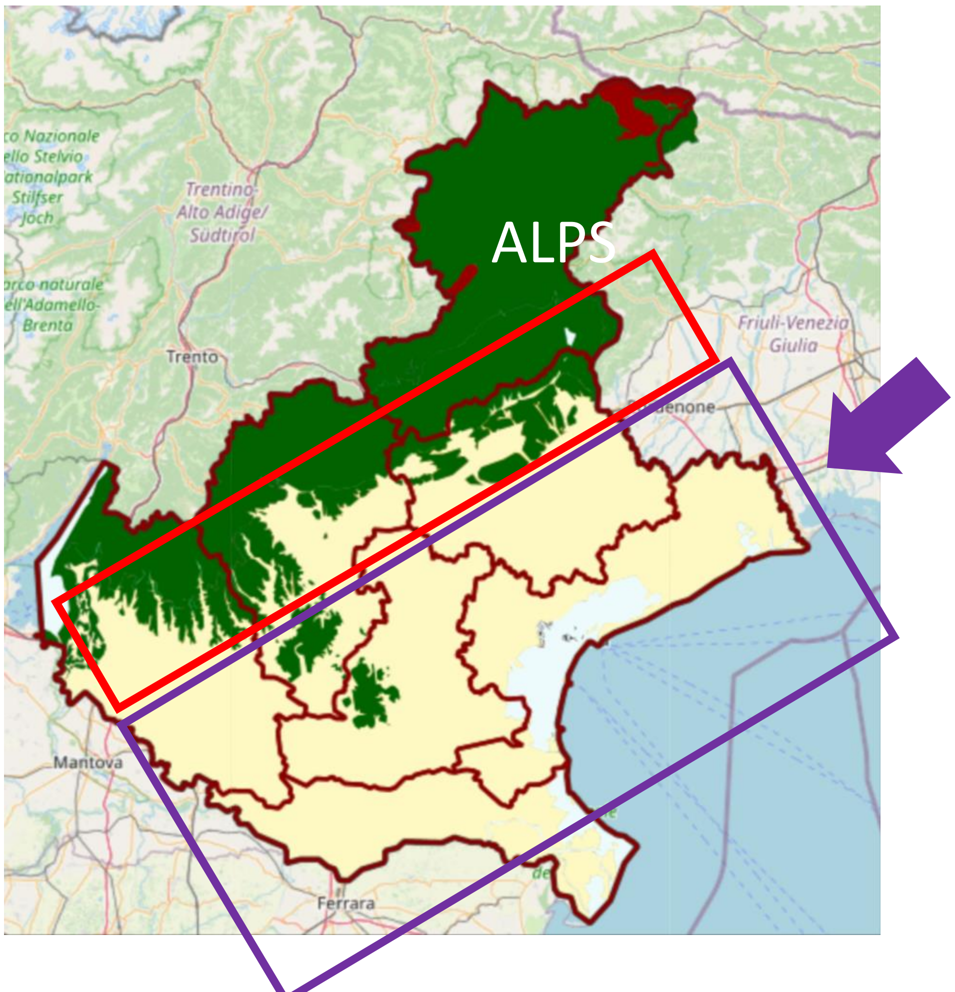
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS



Pre-Alpine zone (variable thickness)

Alluvial Plain zone (thickness greater than 30 meters)

ABACUSES: STEP 1

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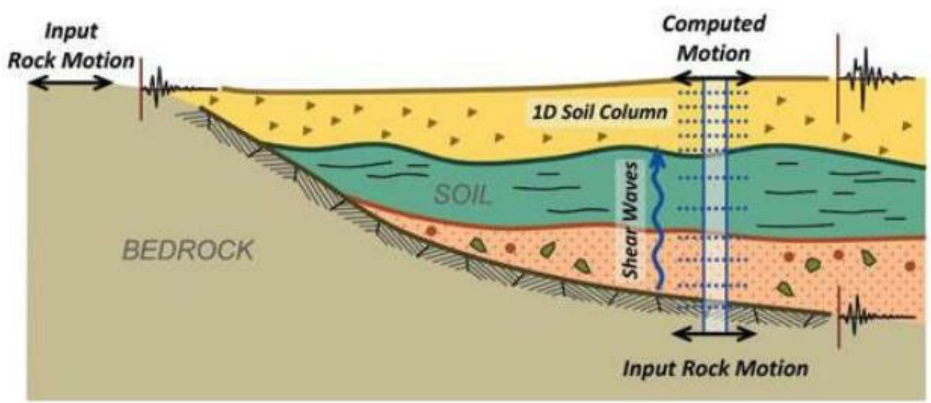
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS



VARIABLE BEDROCK DEPTH OF THE VENETIAN PLAIN:

Retrieve Geophysical information from oil and gas prospection in Veneto Region (1950)

↓

<u>300 m depth</u>

↓

Model the deeper structure with vs gradient

ICMS: Linear Gradient

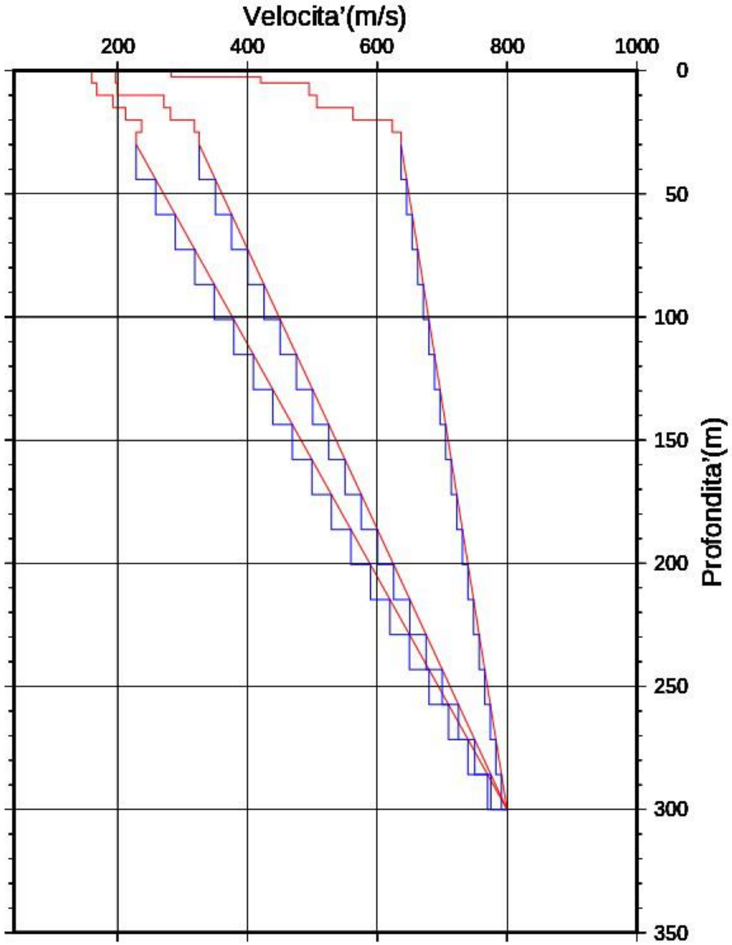
Data
???

30 meters

300 meters

ABACUSES: STEP 1

1.2 GEOPHYSICAL PARAMETERS OF THE UNITS



Representative vs profiles (30 meters)

Linear Grandient (Interpolation between 30 meters and 300 m depth) modelled with slopes and intercepts for each soil category

ABACUSES: STEP 1

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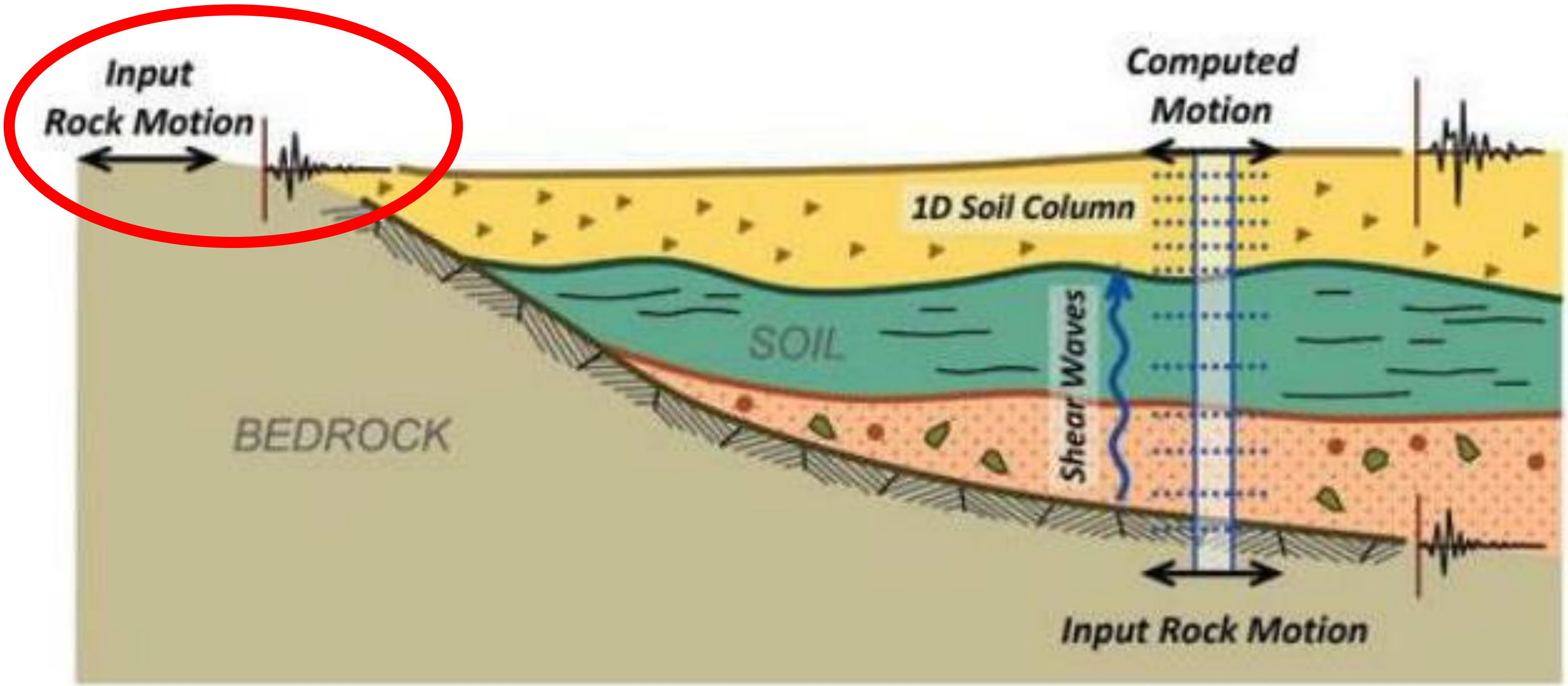
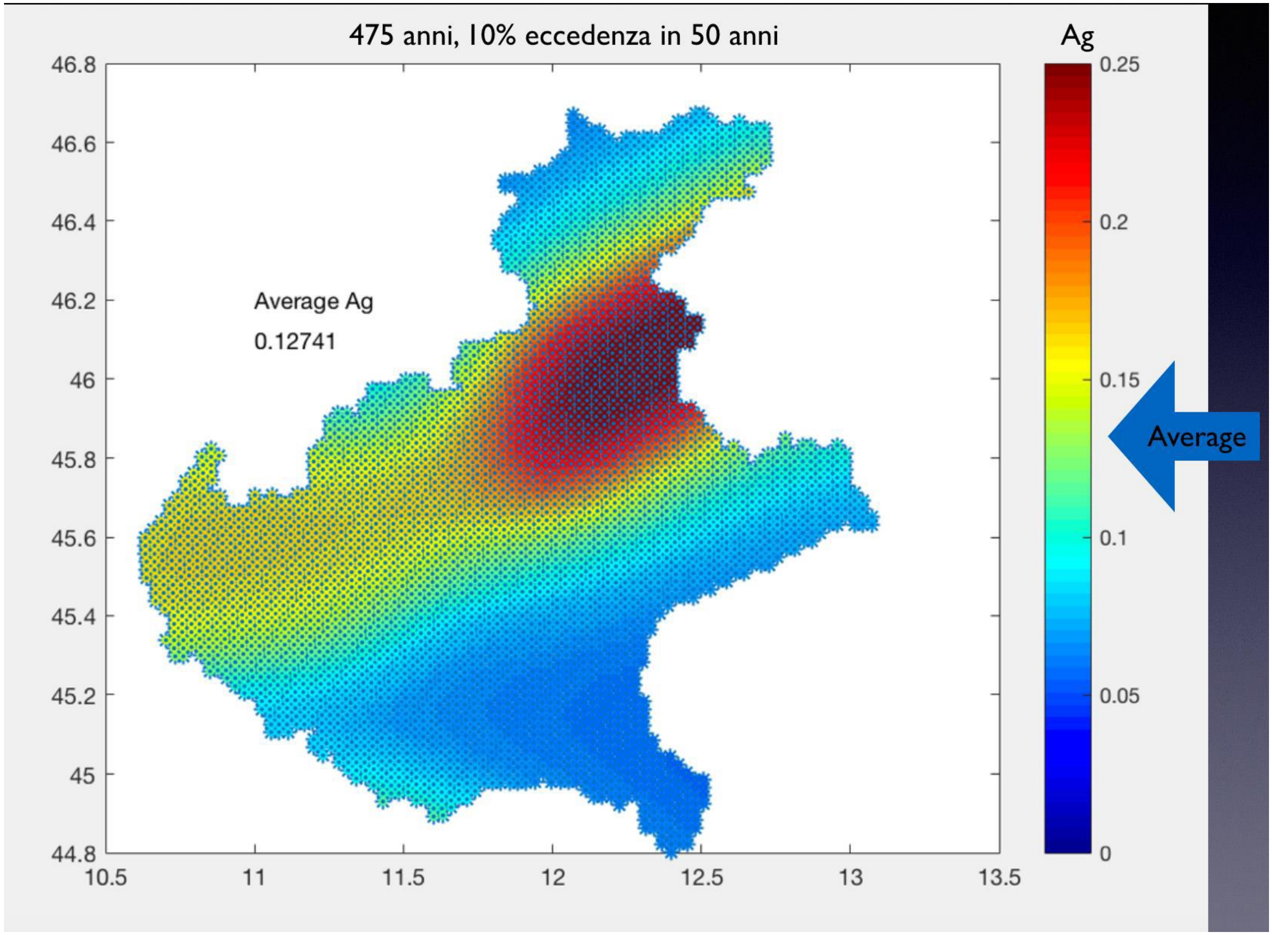
1.3 SEISMIC INPUT SELECTION

Seismic site response analysis requires the definition of seismic input: previously recorded accelerograms. The accelerograms MUST be recorded in bedrock-type formations.



ABACUSES: STEP 1

1.3 SEISMIC INPUT SELECTION



Selection of spectrum-compatible accelerograms

Averaged PGA: 1.27 g

ABACUSES: STEP 1

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1.3 SEISMIC INPUT SELECTION

REXEL PROGRAM:

Real accelerogram compatible with the spectra suggested by the Italian Seismic Codes (Norme Tecniche per le Costruzioni).

Extract set of spectrum-compatible accelerograms from the European Strong Motion Database on the basis of:

- Soil type
- Target spectrum

ABACUSES: STEP 1

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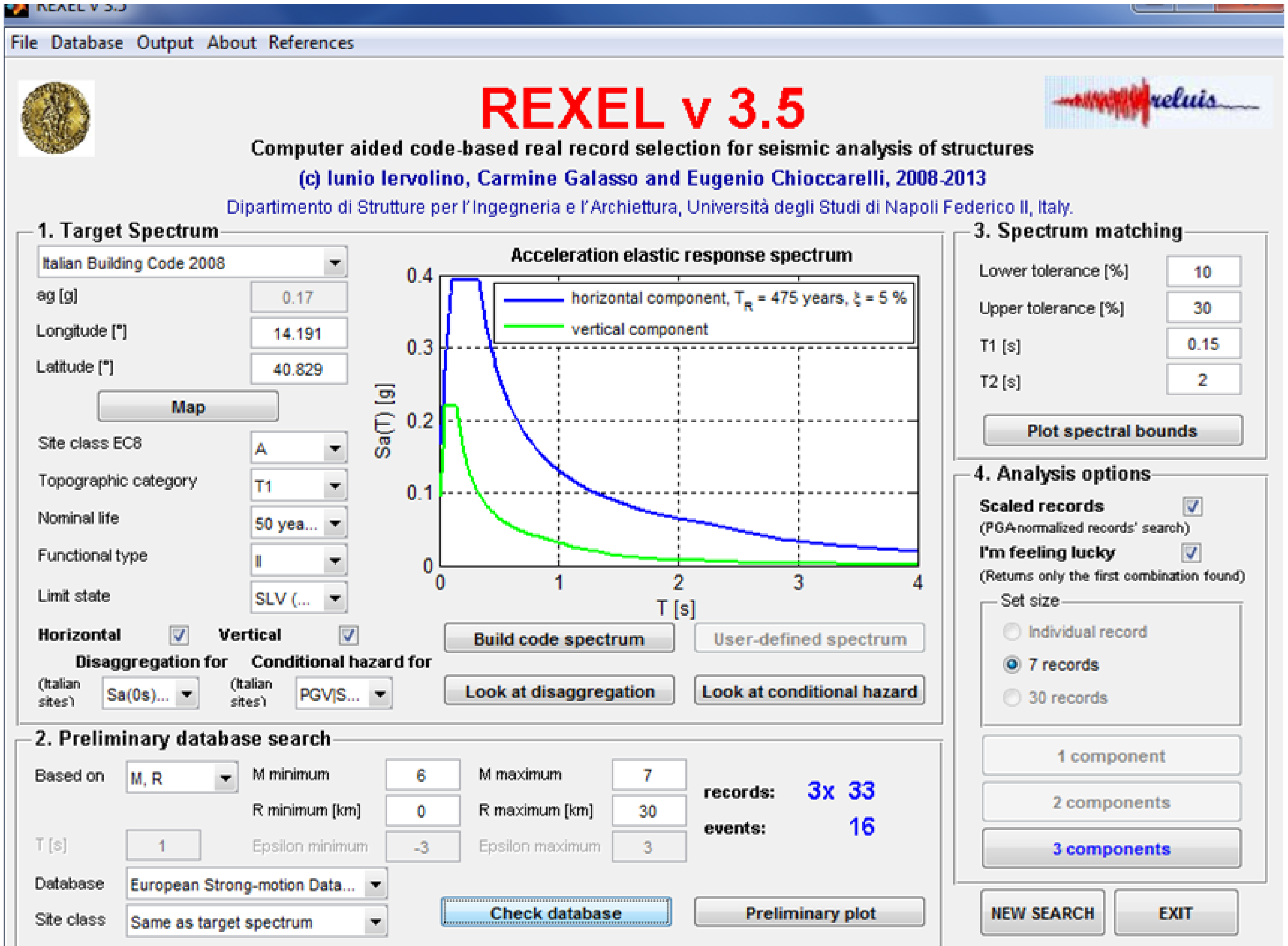
1.3 SEISMIC INPUT SELECTION

Elastic Target Spectrum: Soil type Local Seismic Hazard and Geographic lcation



ABACUSES: STEP 1

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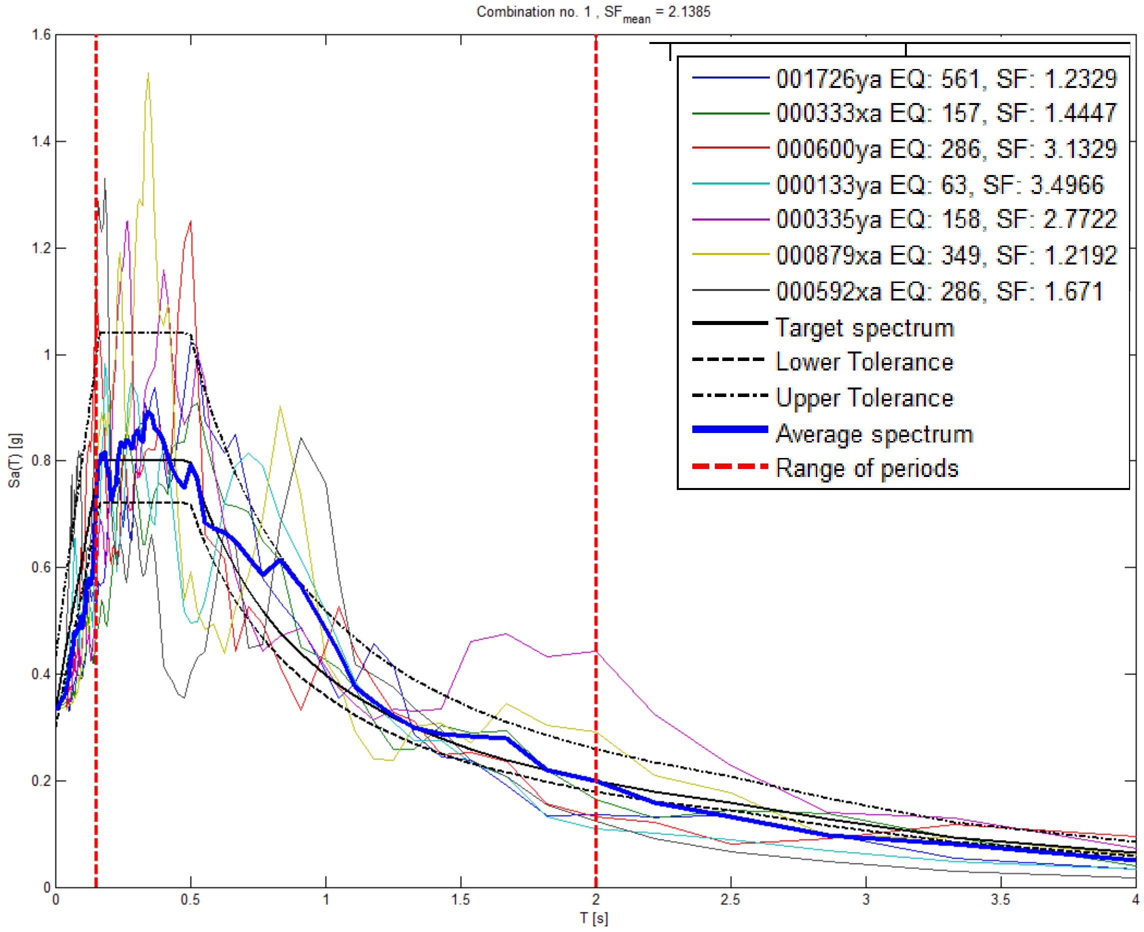
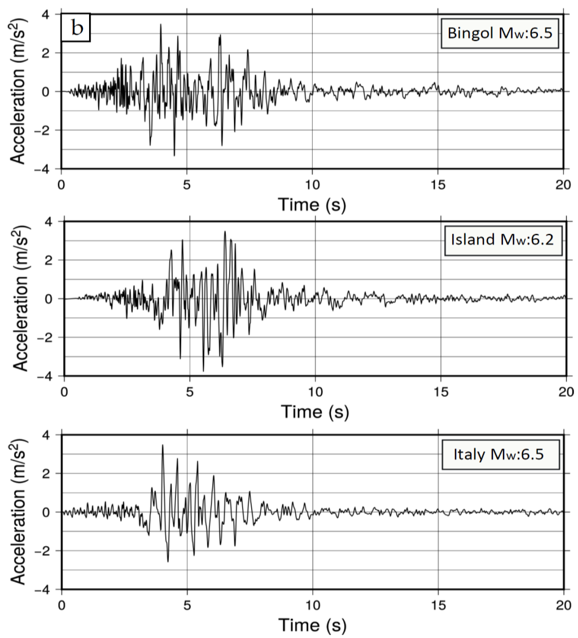
1.3 SEISMIC INPUT SELECTION



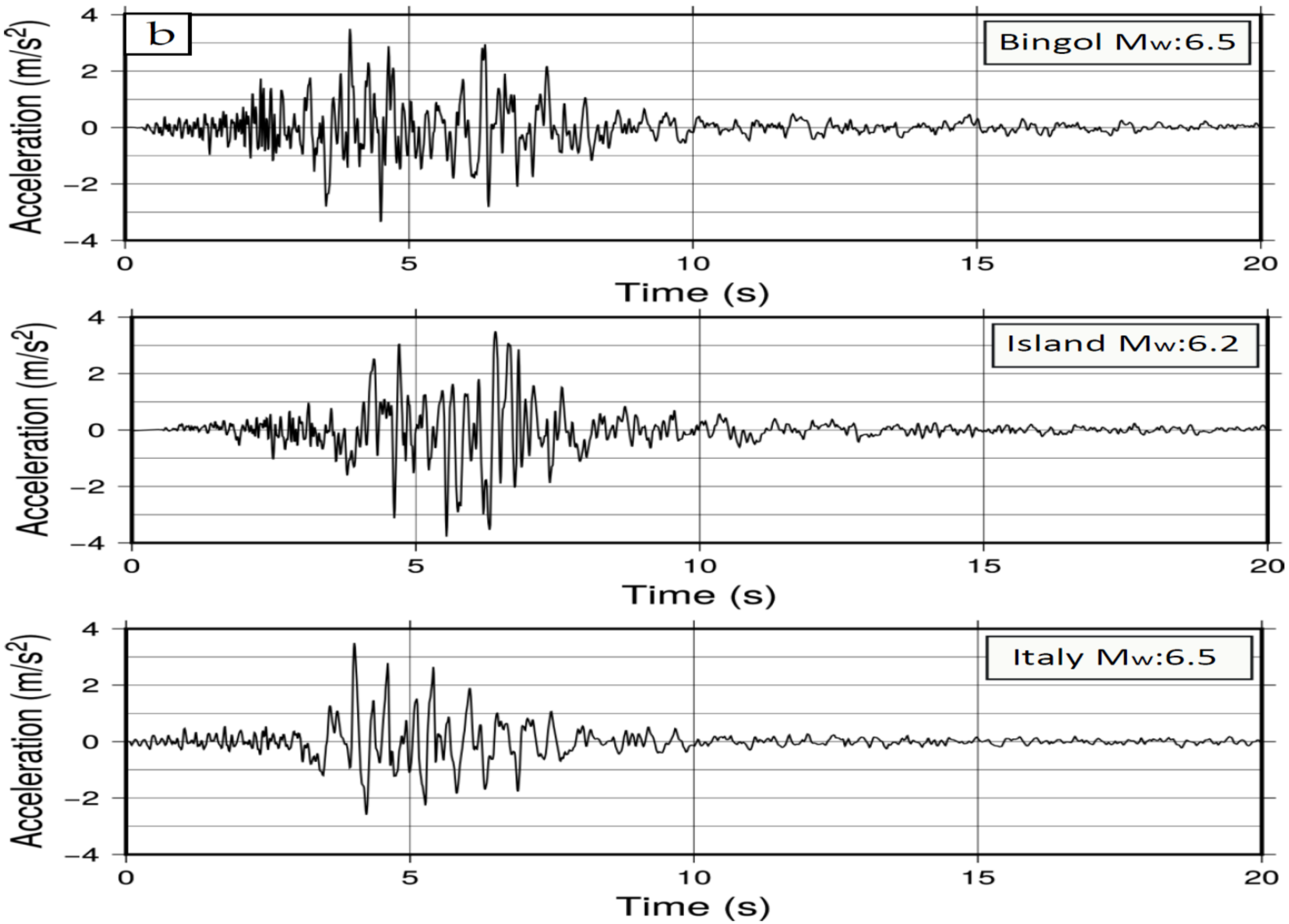
OUTPUT:

- 7 spectro-compatible accelerograms (scaled with the same amplitude)



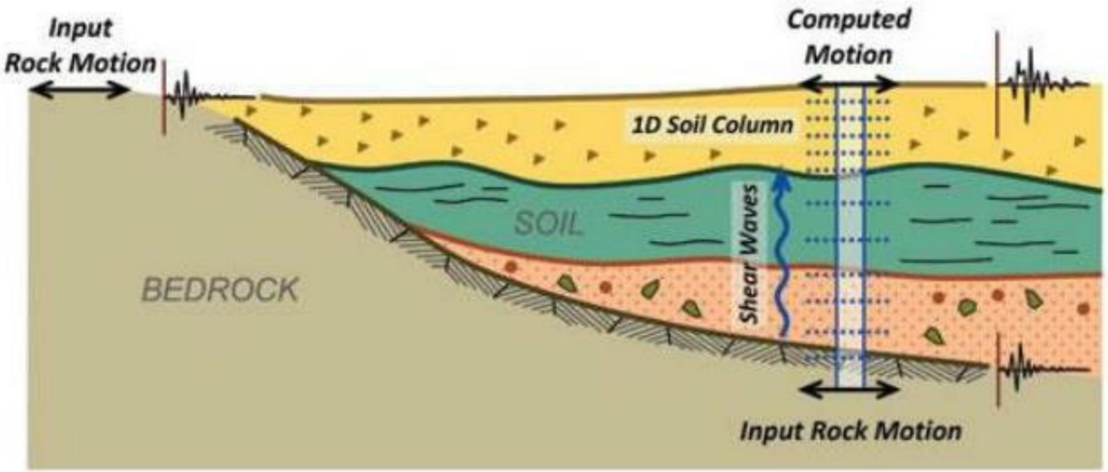
ABACUSES: STEP 1

1.3 SEISMIC INPUT SELECTION



Required information for the estimate of amplification in the II level:

1) Bedrock Depth (or the thickness of alluvial soft soil deposits)
2) Stratigraphic model of the alluvial deposits (vs and non-linear properties)
3) Seismic input



ABACUSES

STEP 1 V

1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS

1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

1.3 SEISMIC INPUT SELECTION

STEP 2

2.1 STRATA SOFTWARE

2.2 AMPLIFICATION FACTOR ESTIMATIONS

2.2 RANDOM GENERATION OF Vs PROFILES

STEP 3

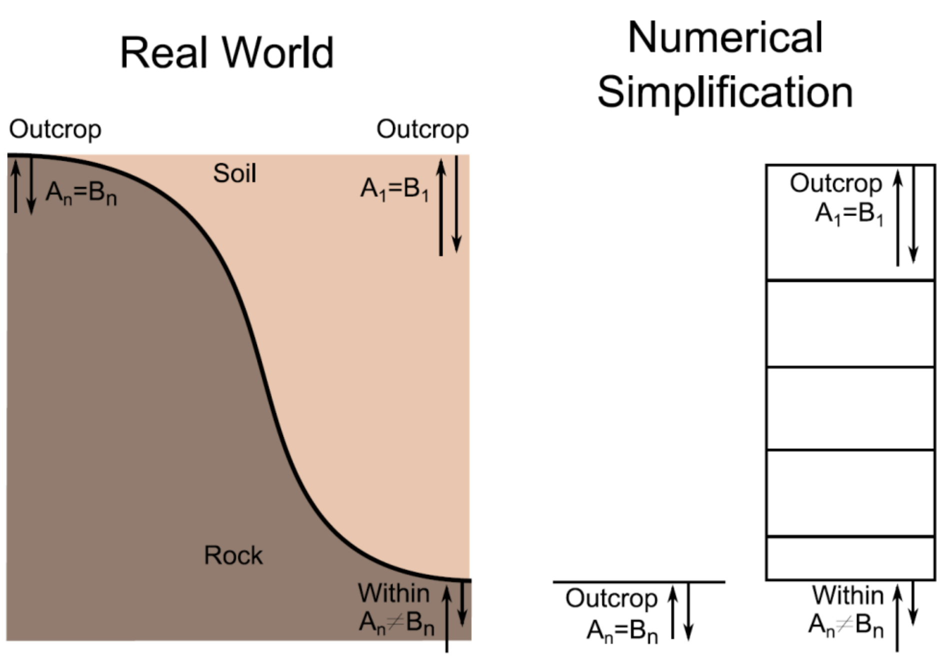
3.1 ABACUSES REALIZATION

ABACUSES: STEP 2

STRATA SOFTWARE

SOFTWARE: **STRATA** (Rattje & Kottle, 2001)

Strata computes the dynamic site response of a one-dimensional soil column using linear wave propagation with strain dependent dynamic soil properties.



Deep Alluvial Basin: 1D Geometry of Horizontal layer

ABACUSES: STEP 2

STRATA SOFTWARE

- Allow 1D seismic site analysis
- Horizontal layer boundaries
- Infinite lateral extension
- Vertically propagating horizontally polarized Shear-waves (SH waves)

ABACUSES: STEP 2

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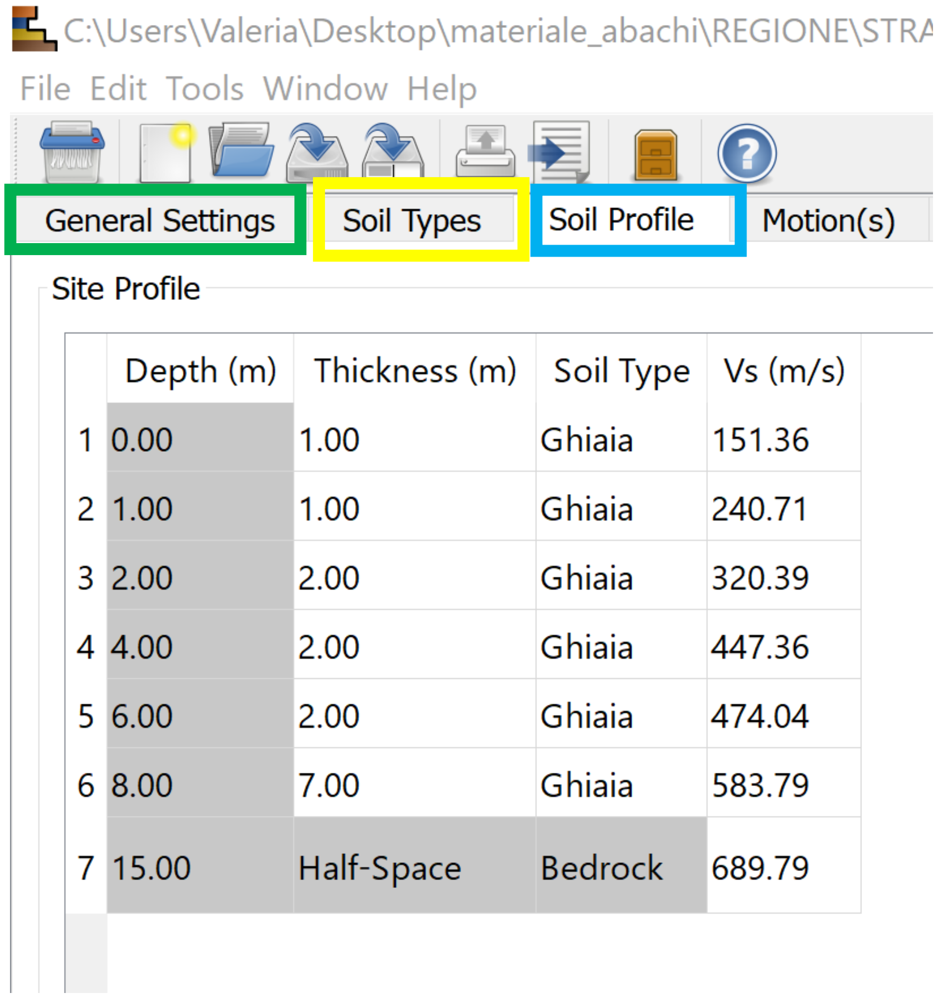
STRATA SOFTWARE

1) General Setting

1) Soil Type: G and D curves and Unit weight (KN/m3)

2) Soil Profile: Average of vs profiles



	Depth (m)	Thickness (m)	Soil Type	Vs (m/s)
1	0.00	1.00	Ghiaia	151.36
2	1.00	1.00	Ghiaia	240.71
3	2.00	2.00	Ghiaia	320.39
4	4.00	2.00	Ghiaia	447.36
5	6.00	2.00	Ghiaia	474.04
6	8.00	7.00	Ghiaia	583.79
7	15.00	Half-Space	Bedrock	689.79

ABACUSES: STEP 2

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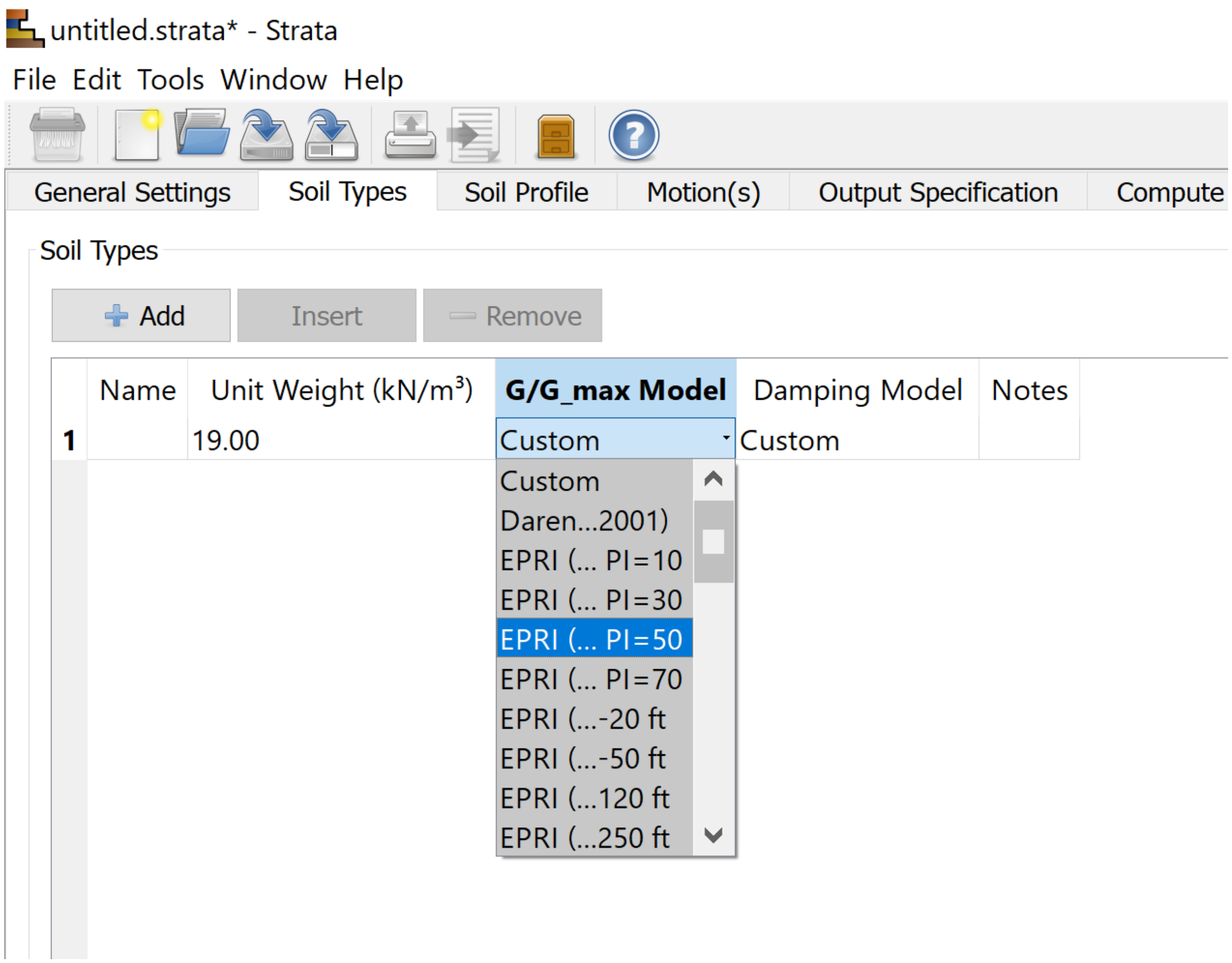
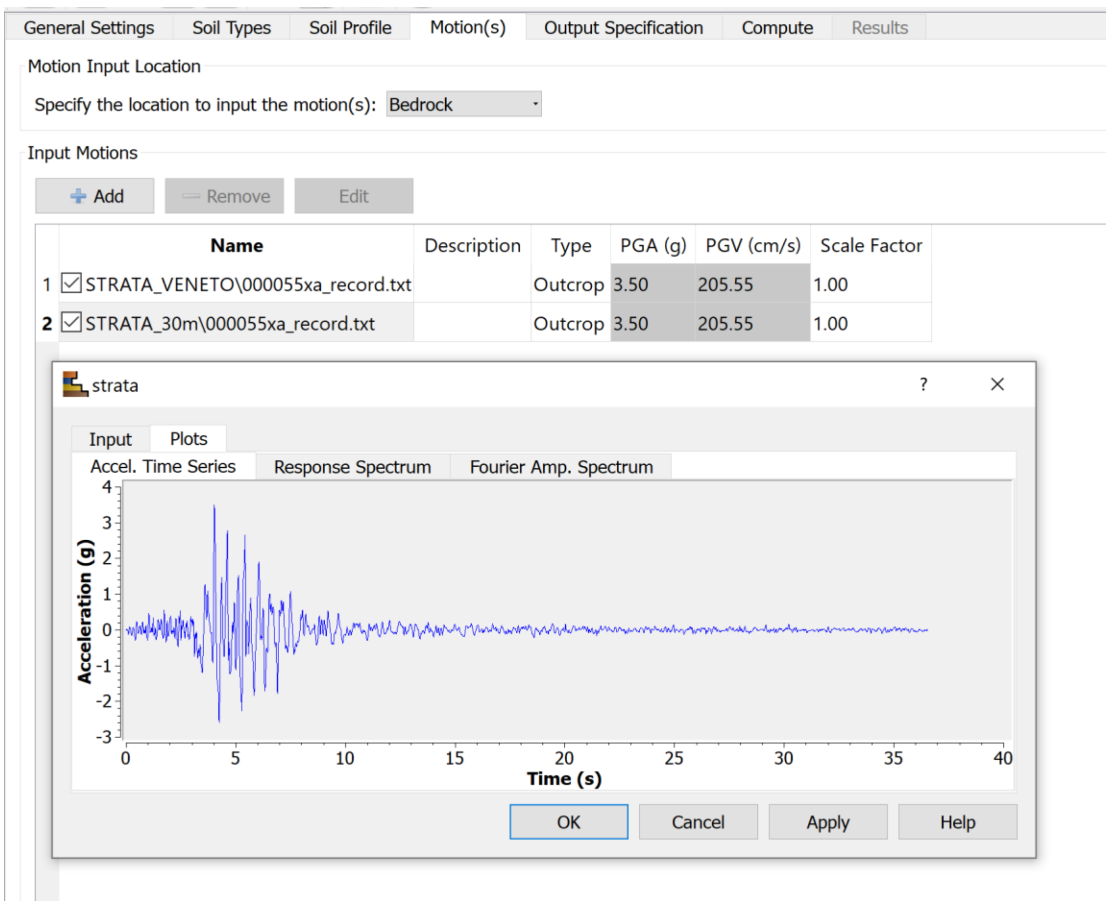
STRATA SOFTWARE



ABACUSES: STEP 2

STRATA SOFTWARE

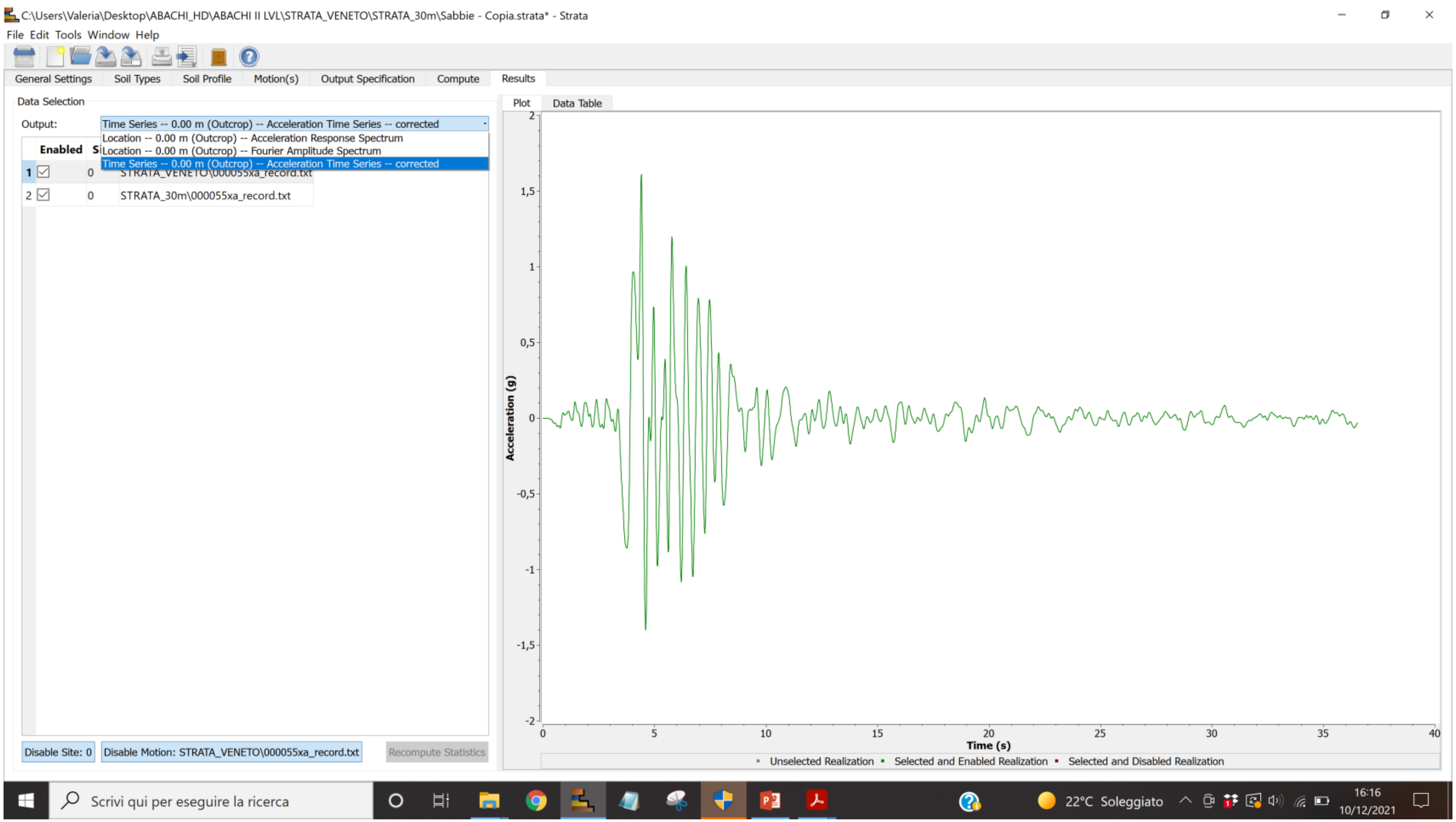
3) SEISMIC INPUT MOTION



ABACUSES: STEP 2

STRATA SOFTWARE

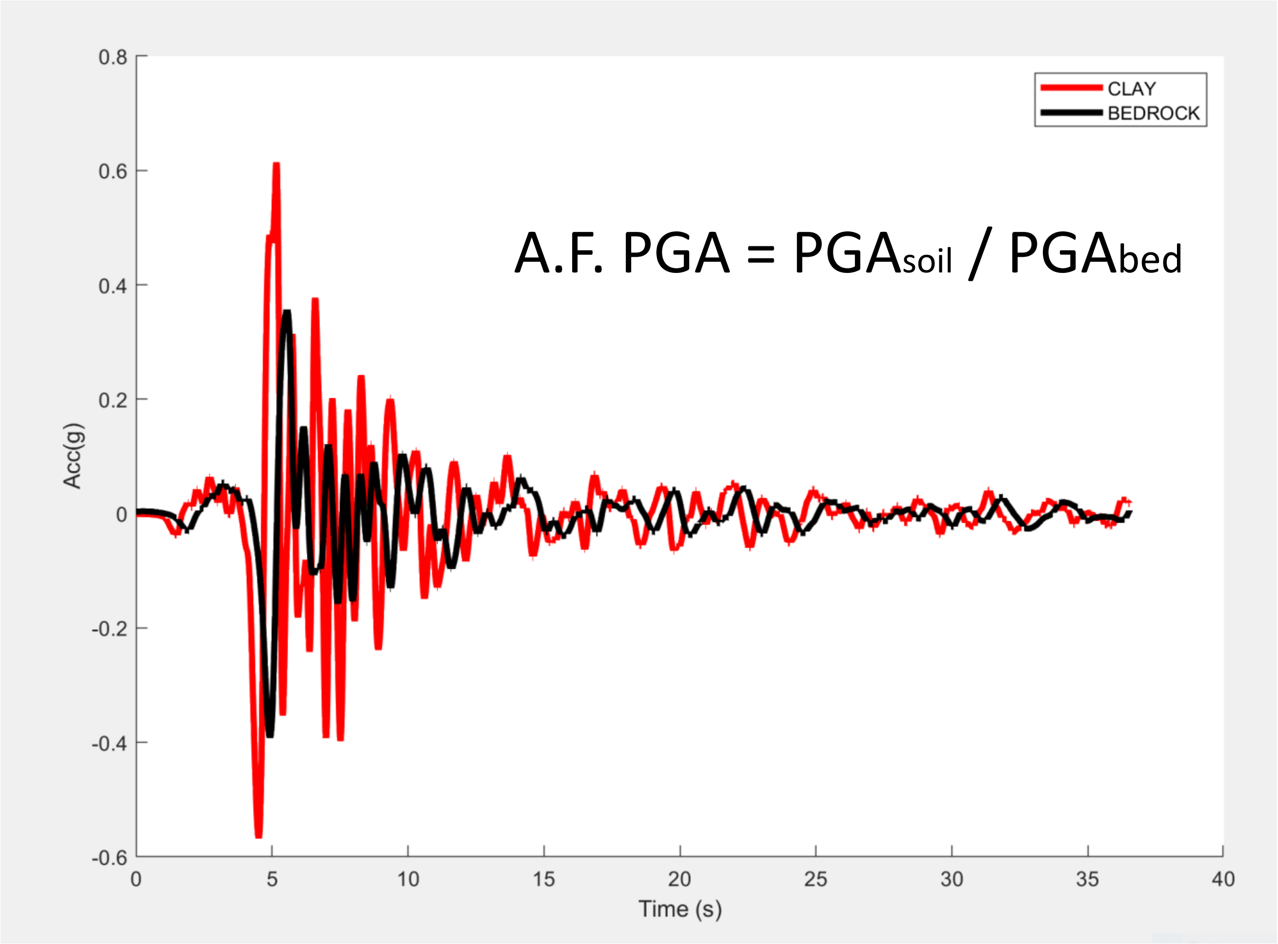
3) OUTPUT



ABACUSES: STEP 2

AMPLIFICATION FACTORS

A.F. PGA



A.F. PGA = PGA_{soil} / PGA_{bed}

ABACUSES: STEP 2

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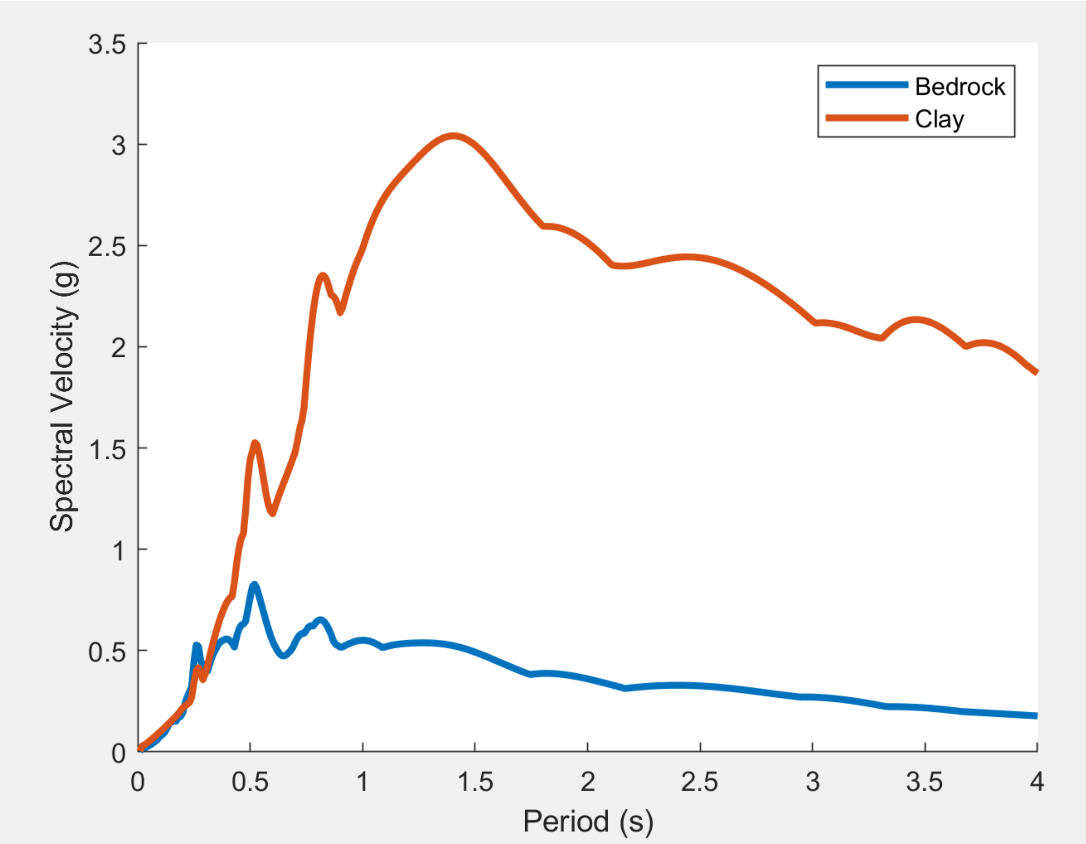
AMPLIFICATION FACTORS

Housner Intensity: Spectral Intensity SI



Paramter adopted in the seismic codes (expressed in cm). Evaluate the seismic input energy and building damage capacity

$$S_I(\xi) = \int_{0.1}^{2.5} Sv(\xi, T)\, dT$$

Sv → Spectral Velocity

ξ → Damping Ratio (5%)

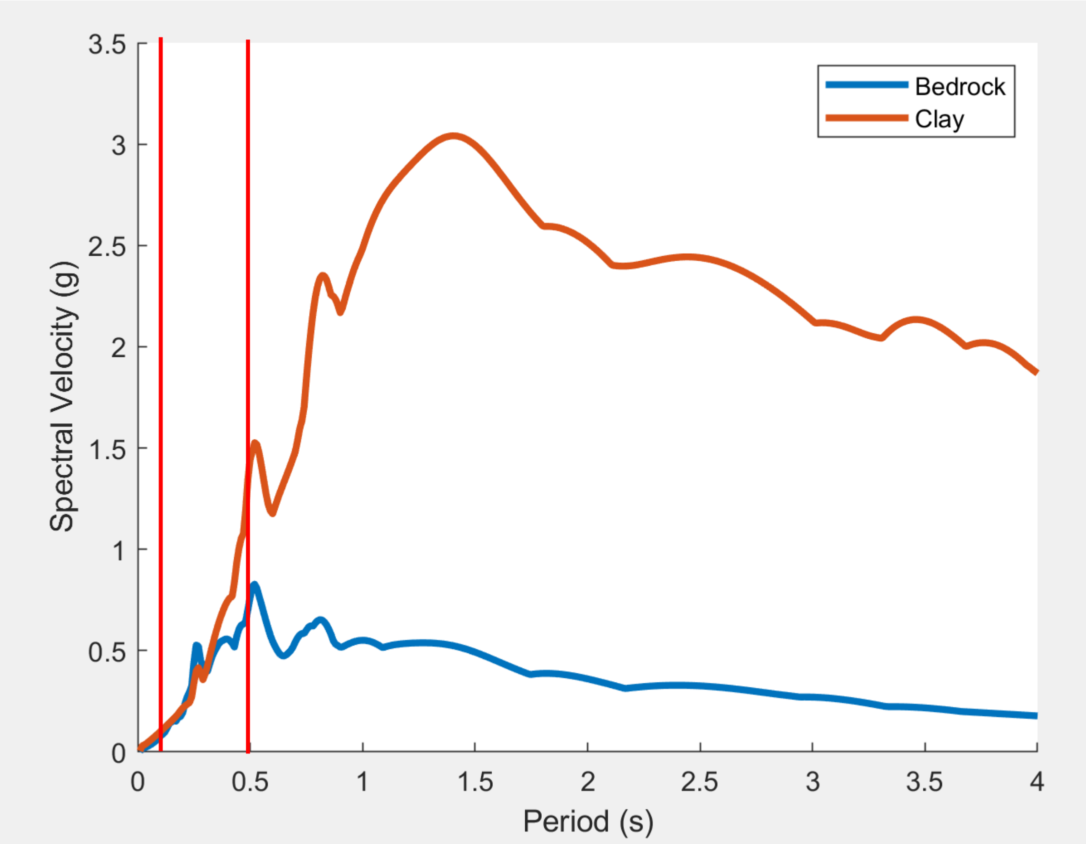
T → Period

The time integral considers the area under the pseudo-velocity response spectra over the period 0.1 – 0.5

ABACUSES: STEP 2

AMPLIFICATION FACTORS

Housner Intensity: Spectral Velocities



$$S_I(\xi) = \int_{0.1}^{2.5} Sv(\xi, T)\, dT$$

Sv → Spectral Velocity

ξ → Damping Ratio (5%)

T → Period

T_1: 0.1 -0.5 s ←

T_2: 0.4 -0.8 s

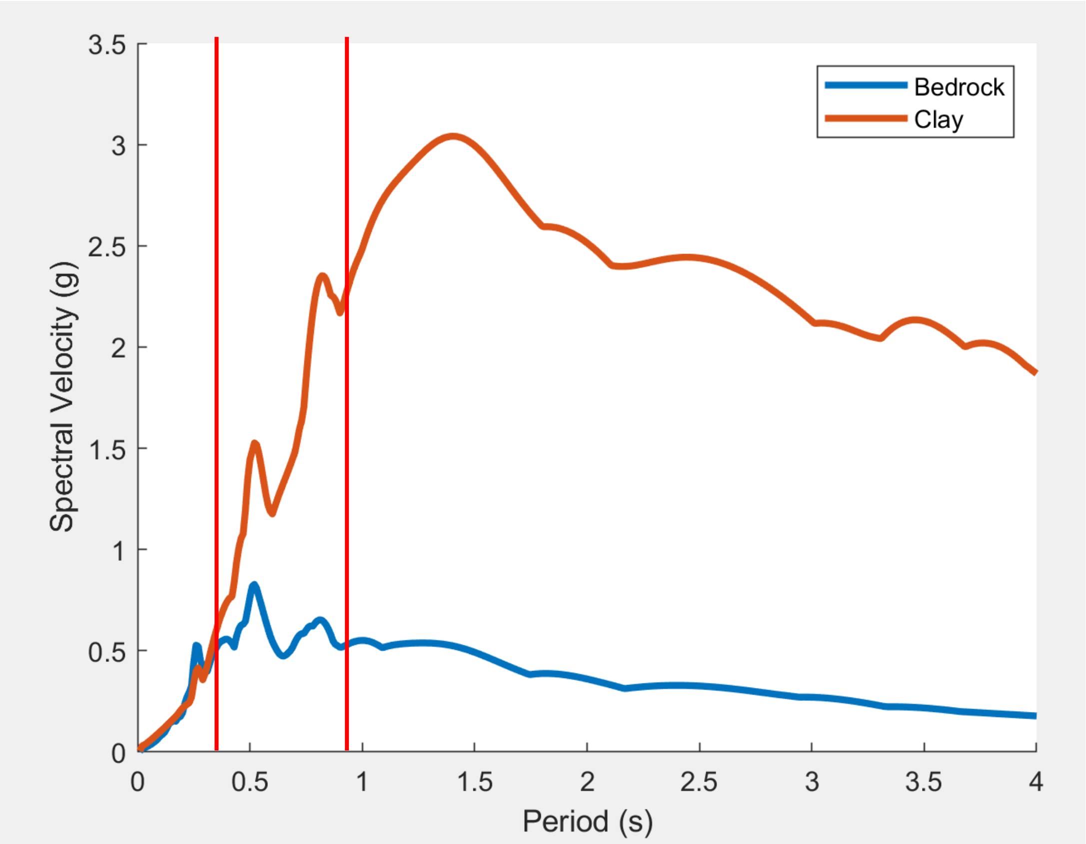
T_3: 0.7- 1.1 s

ABACUSES: STEP 2

Università degli Studi di Padova

AMPLIFICATION FACTORS

Housner Intensity: Spectral Velocities



$$S_I(\xi) = \int_{0.1}^{2.5} Sv\,(\xi, T)\,\mathrm{dT}$$

Sv → Spectral Velocity

ξ → Damping Ratio (5%)

T → Period

T_1: 0.1 -0.5 s

T_2: 0.4 -0.8 s ⇐

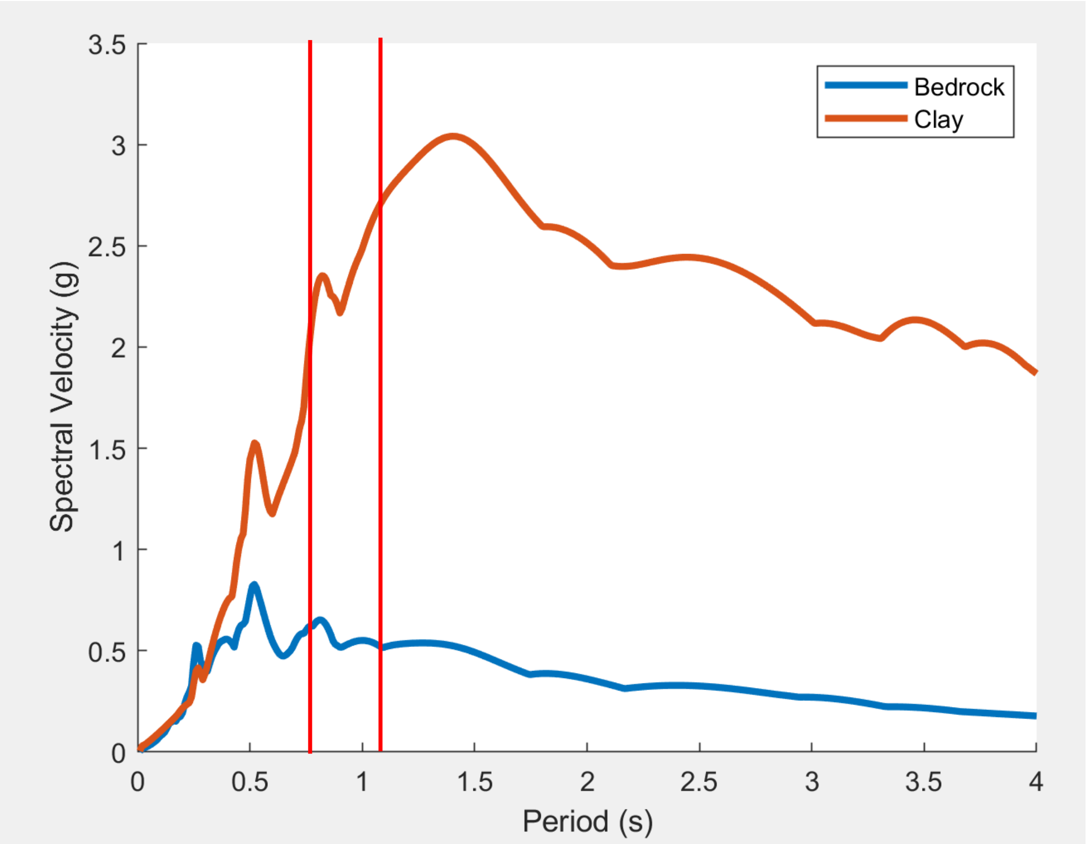
T_3: 0.7- 1.1 s

ABACUSES: STEP 2

UNIVERSITÀ DEGLI STUDI DI PADOVA

AMPLIFICATION FACTORS

Housner Intensity: Spectral Velocities



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T_1: 0.1 -0.5 s

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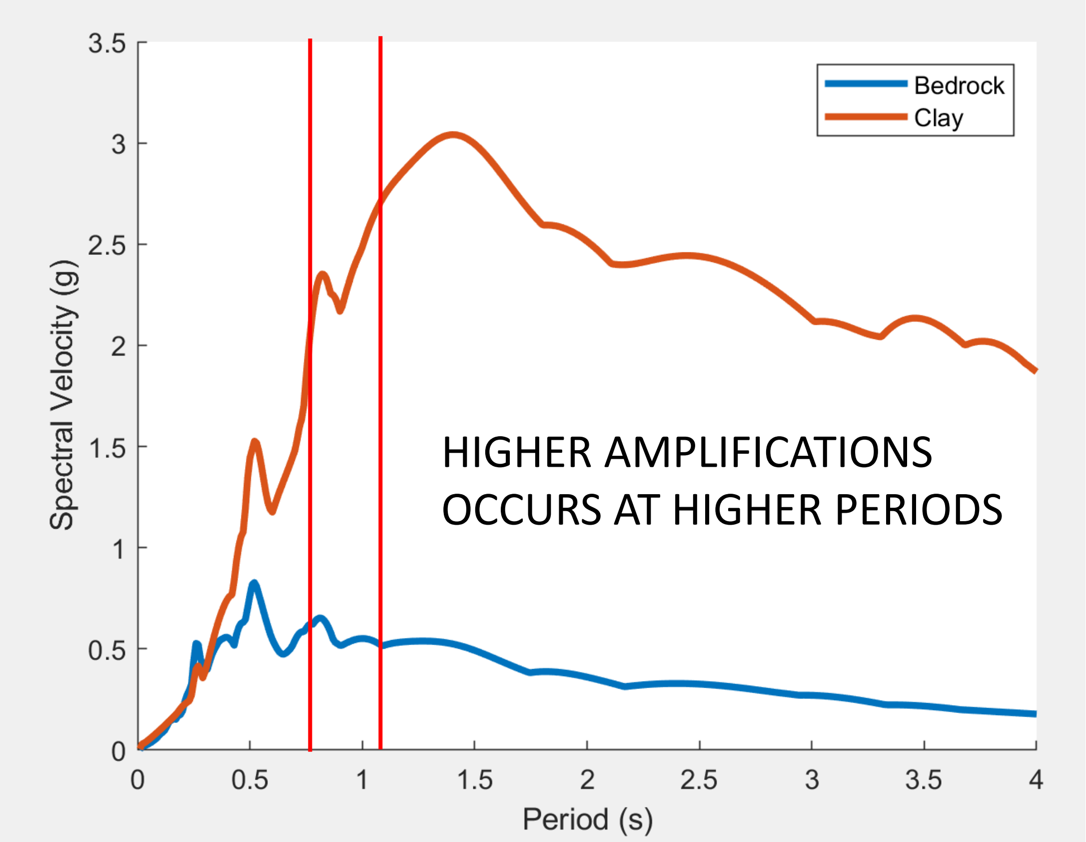
ABACUSES: STEP 2

AMPLIFICATION FACTORS

Housner Intensity: Spectral Velocities



$$S_I(\xi) = \int_{0.1}^{2.5} Sv(\xi, T)\, dT$$

Sv → Spectral Velocity

ξ → Damping Ratio (5%)

T → Period

T_1: 0.1 -0.5 s

T_2: 0.4 -0.8 s

T_3: 0.7- 1.1 s ⬅

ABACUSES: STEP 2

2.1 RANDOM GENERATION OF Vs PROFILES

SOFTWARE: **STRATA** (Rathje & Kottle, 2009)

An estimate of the expected surface response and its standard deviation due to variations in the soil properties can be made through **Monte Carlo simulations**.

Monte Carlo Method: consists of an iterative calculation of deterministic model defined with a set of random realizations. The parameters are randomly generated on the basis of previously defined probability distributions.

ABACUSES: STEP 2

2.1 RANDOM GENERATION OF Vs PROFILES

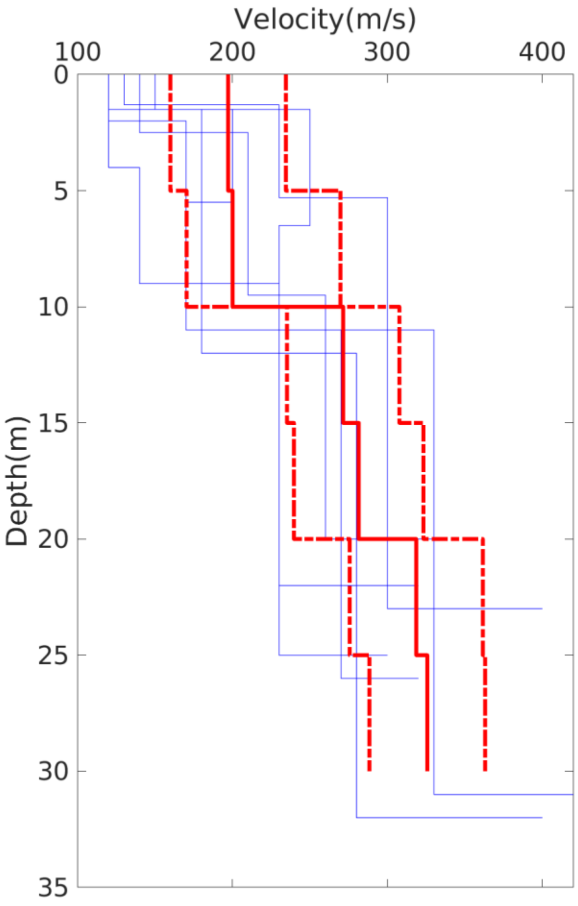
SOFTWARE: **STRATA** (Rathje & Kottle, 2009)

Monte Carlo simulations estimate the response of a system by generating parameters of the system based on defined statistical distributions and computing the response for each set of input parameters.

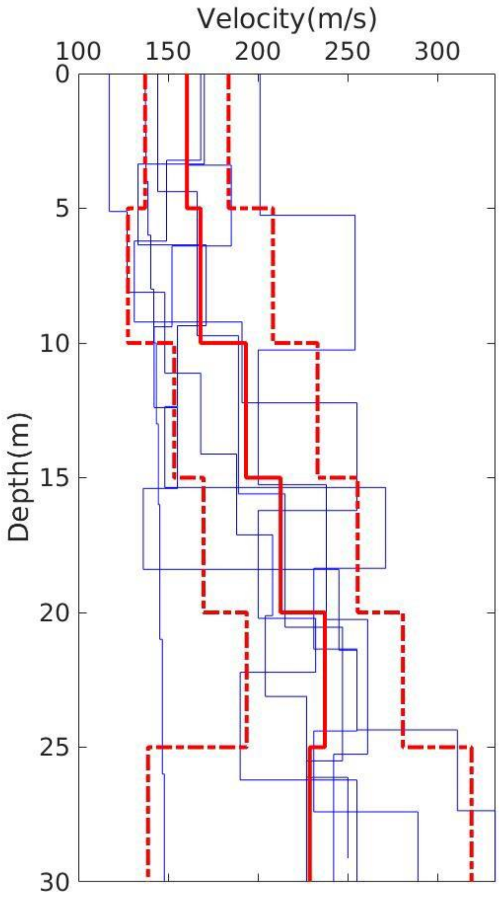
Stochastic site response analysis: Take in account the uncertainty of the measures and the variability of different geological settings.

ABACUSES: STEP 2

SAND



CLAY



ABACUSES: STEP 2

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2.1 RANDOM GENERATION OF Vs PROFILES

Standard deviation of the vs profiles

Site Profile

	Depth (m)	Thickness (m)	Soil Type	Vs (m/s)	Minimum (m/s)	Maximum (m/s)	Varied
1	0.00	5.00	A	160.27	☑ 137.01	☑ 183.52	☑
2	5.00	5.00	A	167.84	☑ 127.44	☑ 208.23	☑
3	10.00	5.00	A	193.17	☑ 153.22	☑ 233.12	☑
4	15.00	5.00	A	212.50	☑ 169.58	☑ 255.45	☑
5	20.00	5.00	A	237.13	☑ 193.61	☑ 280.65	☑
6	25.00	5.00	A	228.74	☑ 190.61	☑ 250.00	☑
7	30.00	Half-Space	Bedrock	250.00	☐ 0.00	☐ 0.00	☐

ABACUSES: STEP 2

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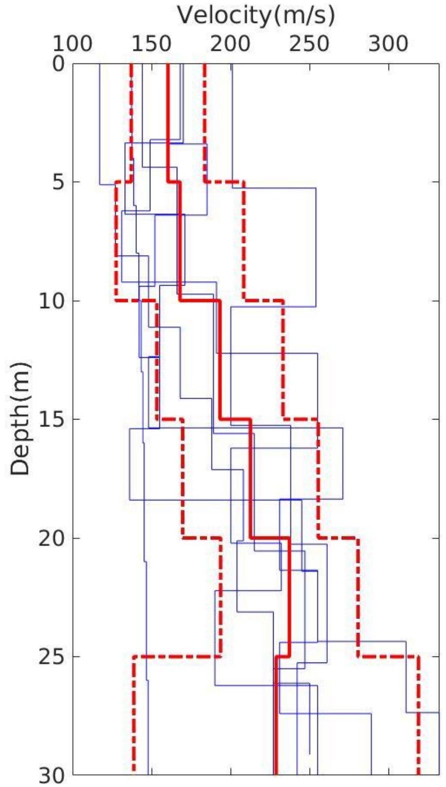
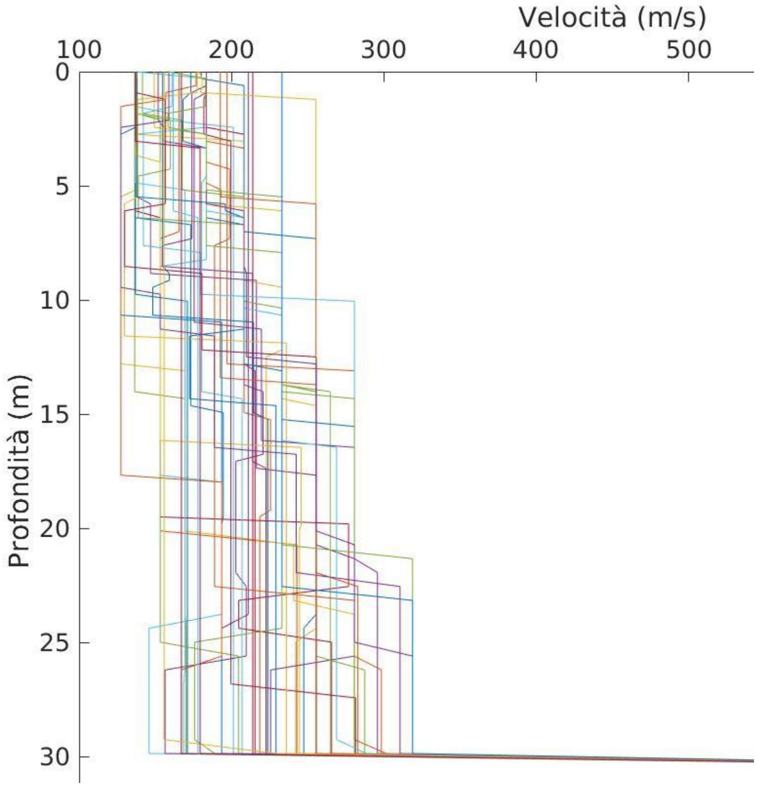
2.1 RANDOM GENERATION OF Vs PROFILES

Monte Carlo simulations is applied to site response analysis in order to take in account the variability of the shear-wave velocities

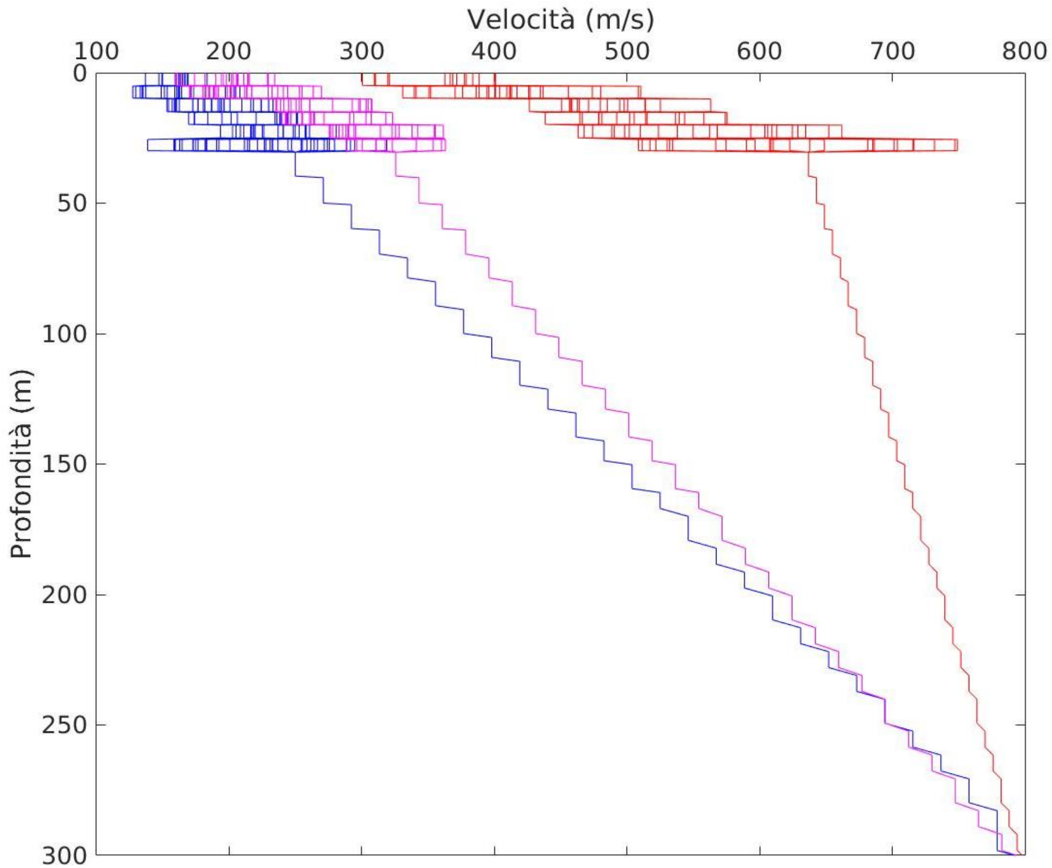




ABACUSES: STEP 2

UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 RANDOM GENERATION OF Vs PROFILES



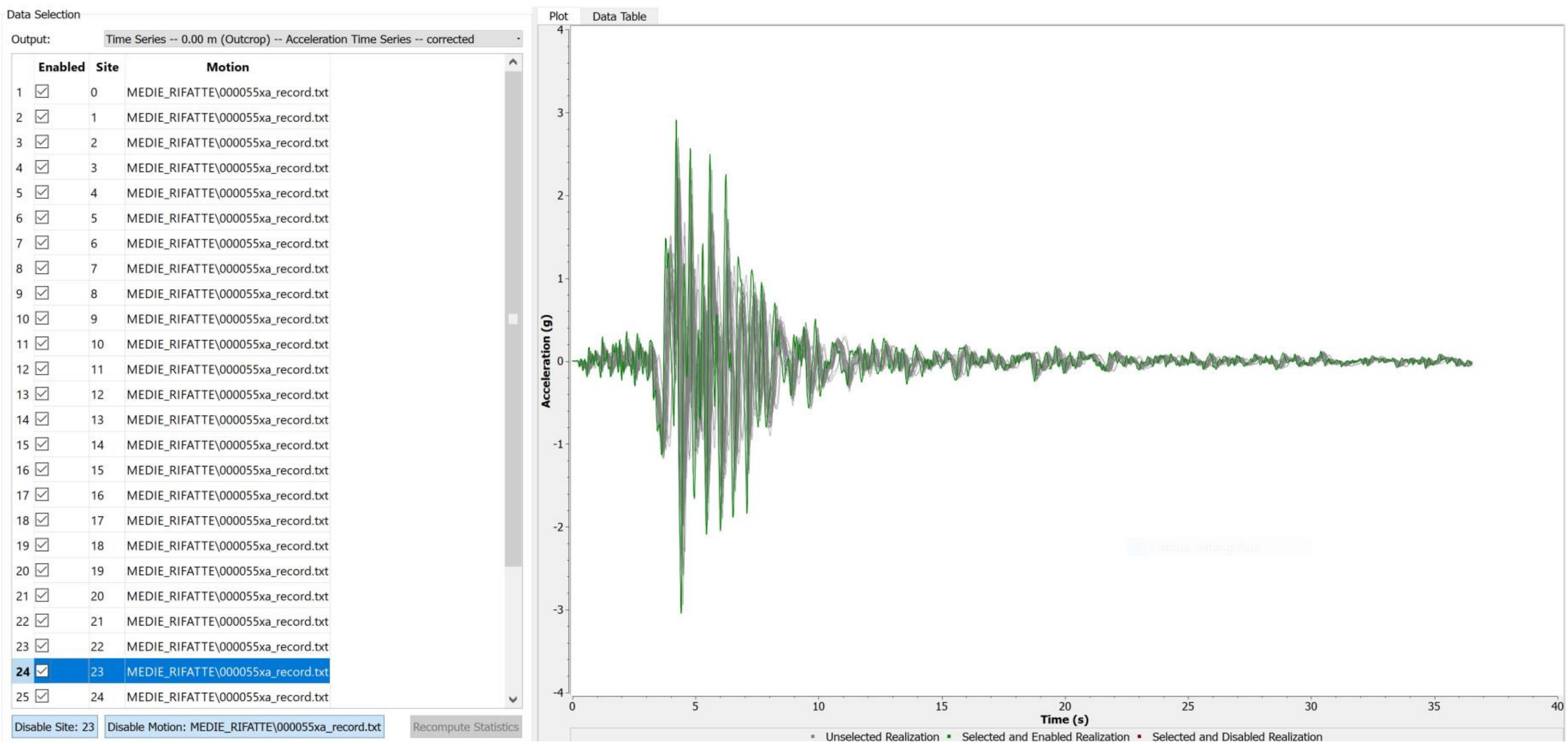
Deep Alluvial Plain:

We change the soil properties only in the upper 30 meters

ABACUSES: STEP 2

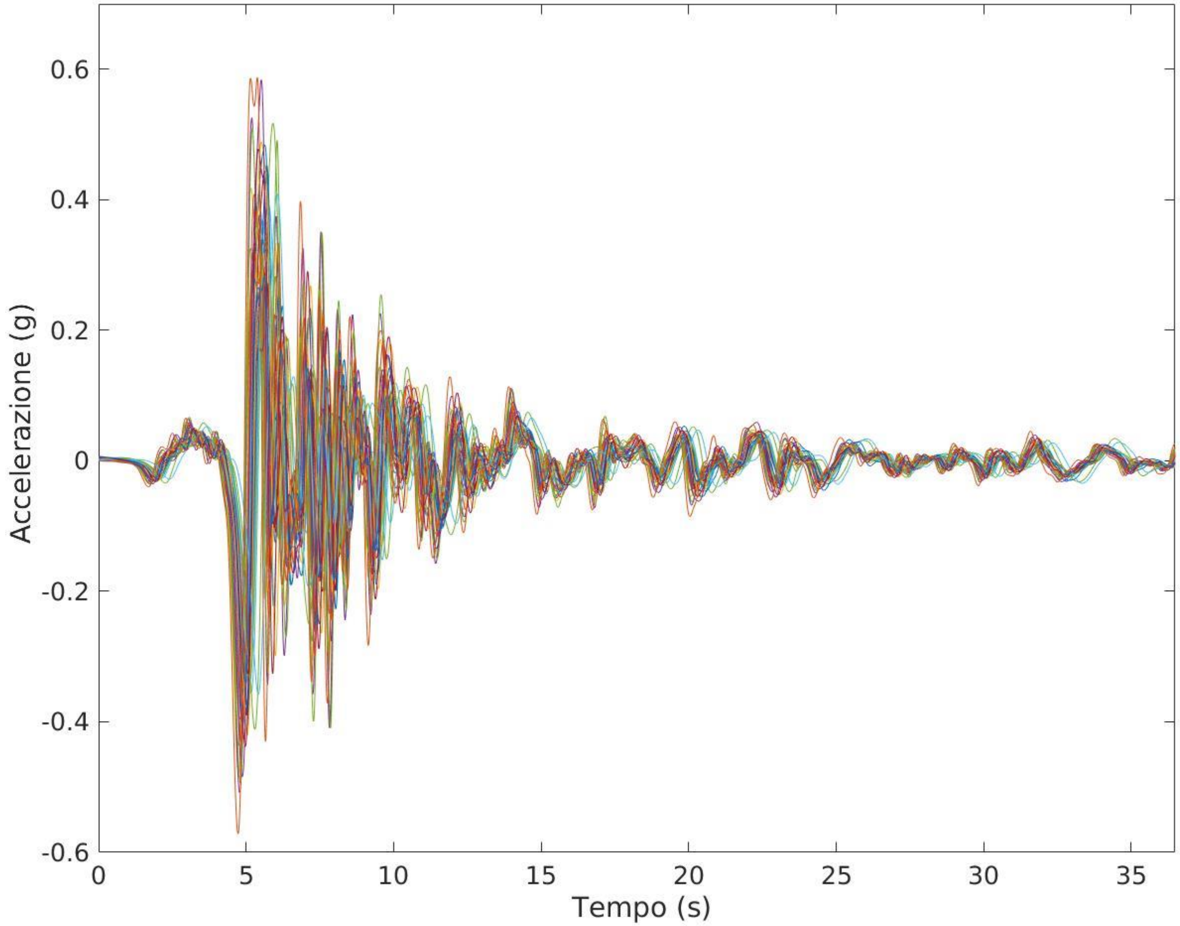
UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 RANDOM GENERATION OF Vs PROFILES



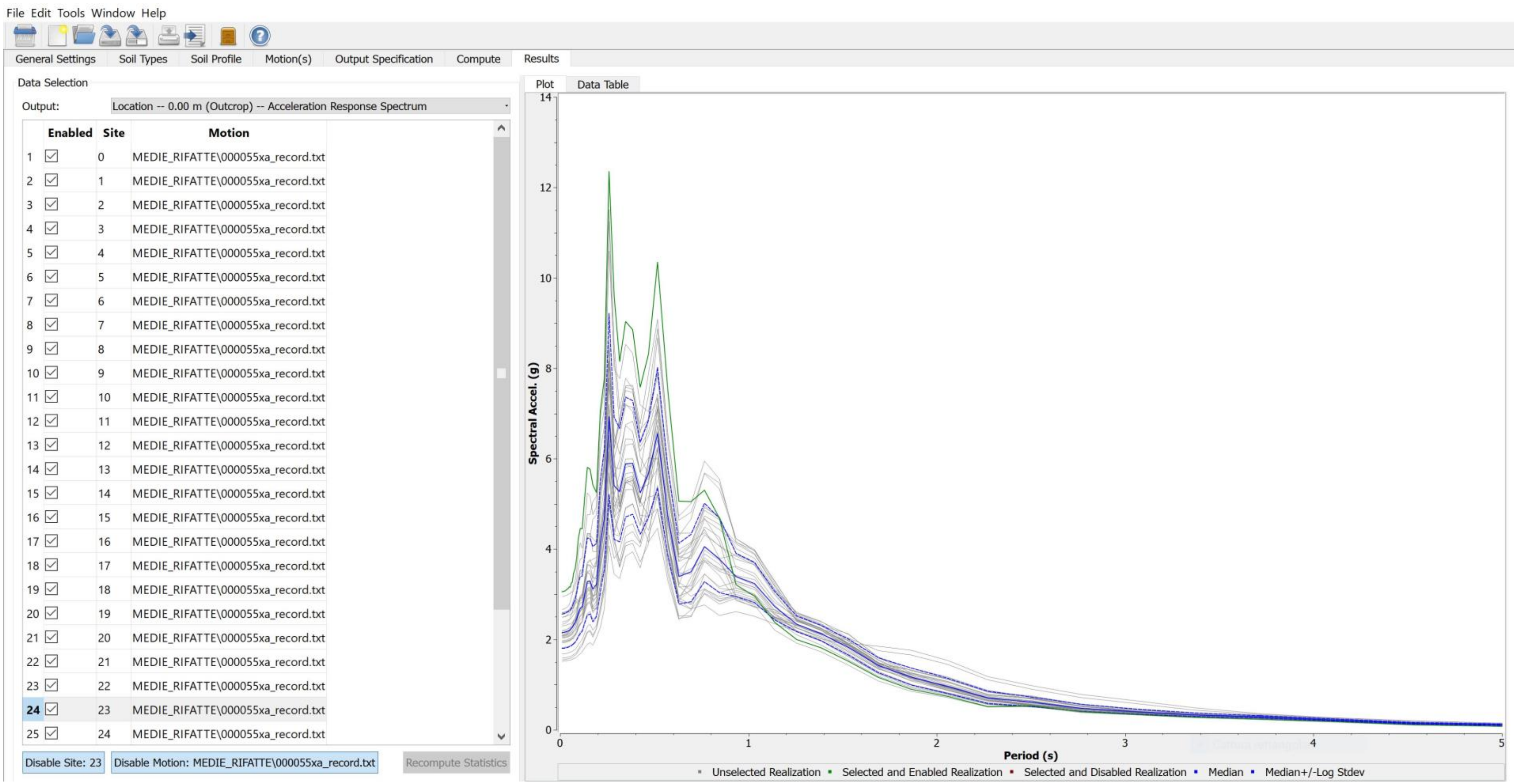
ABACUSES: STEP 2

2.1 RANDOM GENERATION OF Vs PROFILES



ABACUSES: STEP 2

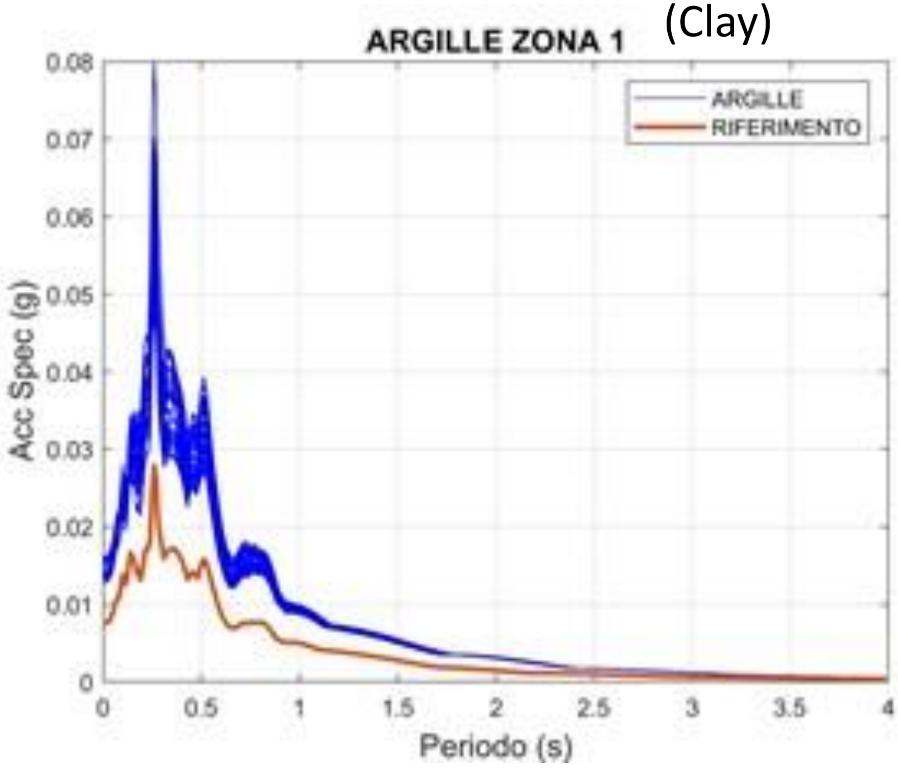
2.1 RANDOM GENERATION OF Vs PROFILES



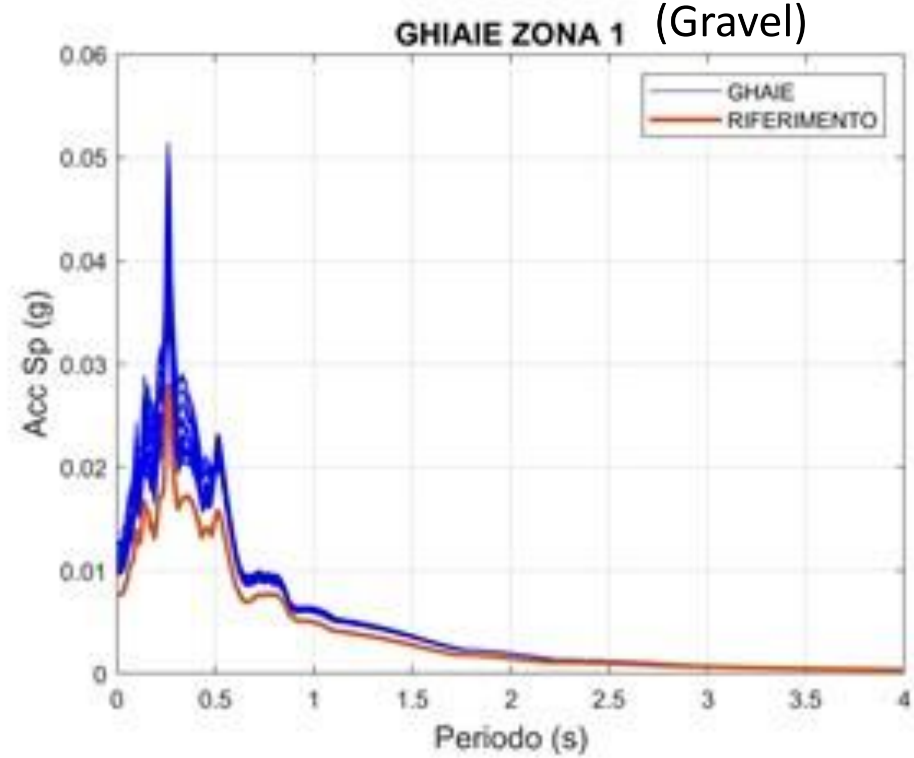
ABACUSES: STEP 2

2.1 RANDOM GENERATION OF Vs PROFILES

(Clay)



(Gravel)



ABACUSES

STEP 1 V

- 1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS
- 1.2 GEOPHYSICAL PARAMETERS OF THE UNITS
- 1.3 SEISMIC INPUT SELECTION

STEP 2 V

- 2.1 STRATA SOFTWARE
- 2.2 AMPLIFICATION FACTOR ESTIMATIONS
- 2.2 RANDOM GENERATION OF Vs PROFILES

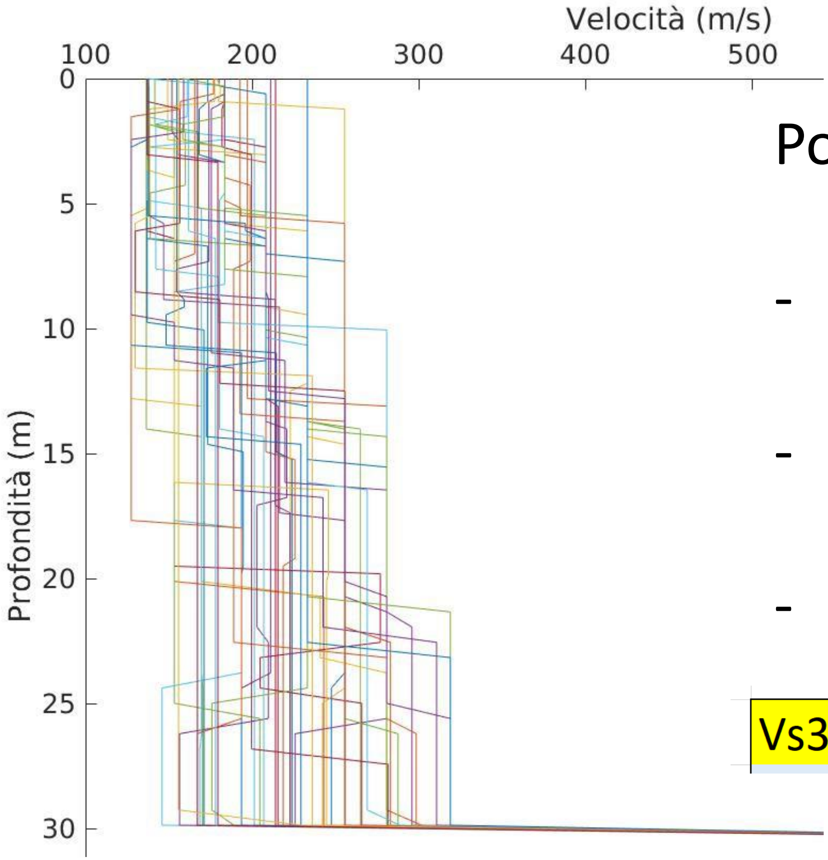
STEP 3

- 3.1 ABACUSES REALIZATION

ABACUSES: STEP 3

3.1 ABACUSES

$$Vs_{30} = \frac{30}{\sum \frac{h_i}{Vs_i}}$$



Population of vs profiles:

- 150 < vs30 < 200
- 200 < vs30 < 250
- 250 < vs30 < 300

Vs30(m/s)	200	250	300

ABACUSES: STEP 2

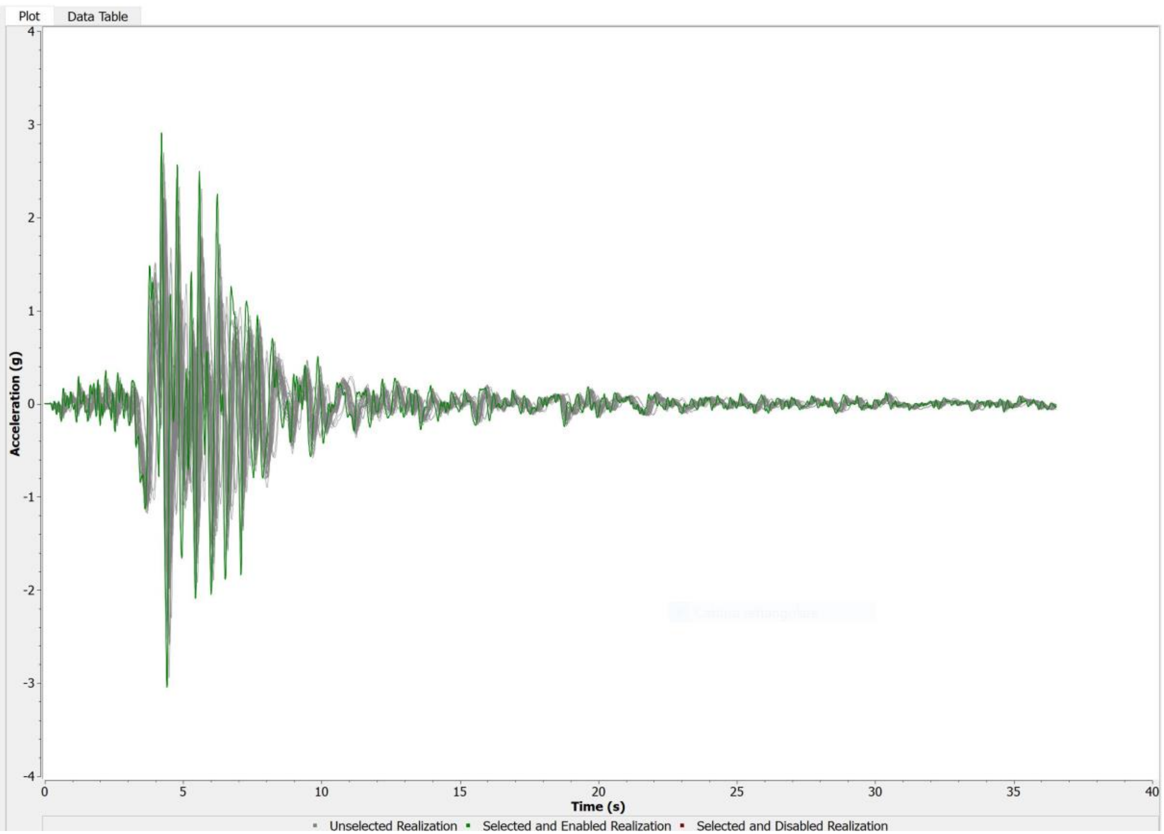
2.1 RANDOM GENERATION OF Vs PROFILES

Data Selection

Output: Time Series -- 0.00 m (Outcrop) -- Acceleration Time Series -- corrected

	Enabled	Site	Motion
1	☑	0	MEDIE_RIFATTE\000055xa_record.txt
2	☑	1	MEDIE_RIFATTE\000055xa_record.txt
3	☑	2	MEDIE_RIFATTE\000055xa_record.txt
4	☑	3	MEDIE_RIFATTE\000055xa_record.txt
5	☑	4	MEDIE_RIFATTE\000055xa_record.txt
6	☑	5	MEDIE_RIFATTE\000055xa_record.txt
7	☑	6	MEDIE_RIFATTE\000055xa_record.txt
8	☑	7	MEDIE_RIFATTE\000055xa_record.txt
9	☑	8	MEDIE_RIFATTE\000055xa_record.txt
10	☑	9	MEDIE_RIFATTE\000055xa_record.txt
11	☑	10	MEDIE_RIFATTE\000055xa_record.txt
12	☑	11	MEDIE_RIFATTE\000055xa_record.txt
13	☑	12	MEDIE_RIFATTE\000055xa_record.txt
14	☑	13	MEDIE_RIFATTE\000055xa_record.txt
15	☑	14	MEDIE_RIFATTE\000055xa_record.txt
16	☑	15	MEDIE_RIFATTE\000055xa_record.txt
17	☑	16	MEDIE_RIFATTE\000055xa_record.txt
18	☑	17	MEDIE_RIFATTE\000055xa_record.txt
19	☑	18	MEDIE_RIFATTE\000055xa_record.txt
20	☑	19	MEDIE_RIFATTE\000055xa_record.txt
21	☑	20	MEDIE_RIFATTE\000055xa_record.txt
22	☑	21	MEDIE_RIFATTE\000055xa_record.txt
23	☑	22	MEDIE_RIFATTE\000055xa_record.txt
24	☑	23	MEDIE_RIFATTE\000055xa_record.txt
25	☑	24	MEDIE_RIFATTE\000055xa_record.txt

Disable Site: 23 | Disable Motion: MEDIE_RIFATTE\000055xa_record.txt | Recompute Statistics

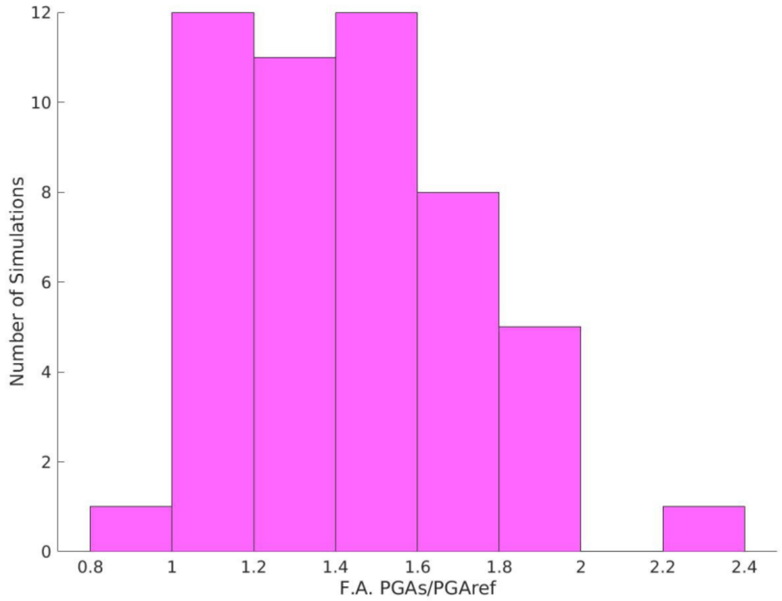


ABACUSES: STEP 3

3.1 ABACUSES

Example: 250 < vs30 < 350

For each profile included in this range we estimate the Amplification Factor of PGA and we estimate the mean. In this case the mean is equal to 1.6

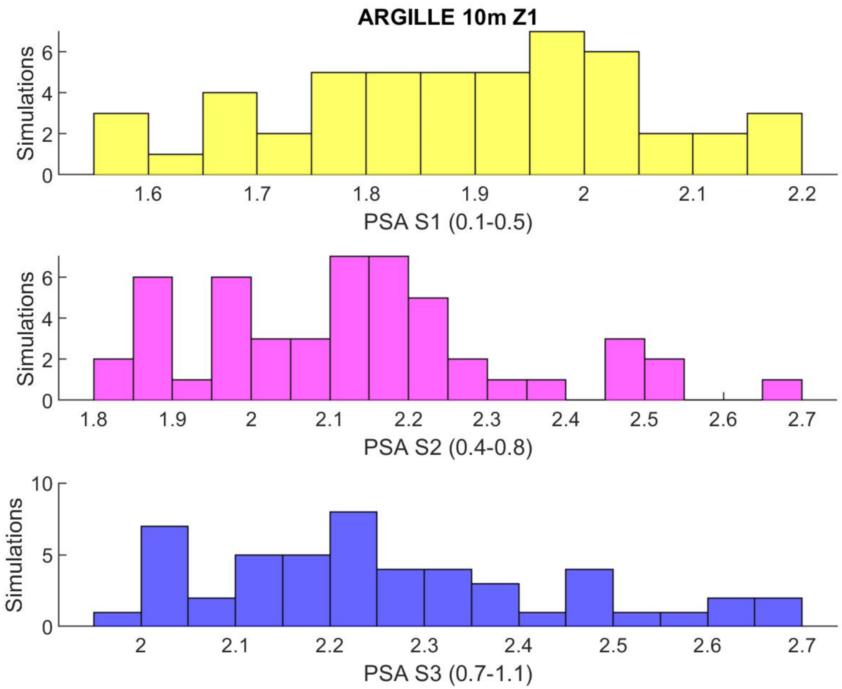


Vs30(m/s)	200	250	300
F.A. PGA	1.8	1.7	1.6

ABACUSES: STEP 3

UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 STATISTICAL ANALYSIS



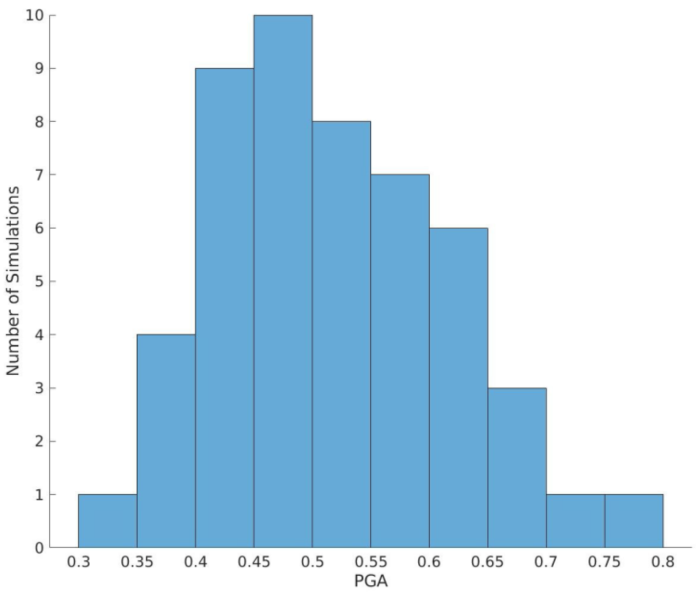
Vs30(m/s)	200	250	300
F.A. PGA	1.8	1.7	1.6
F.A. S1	1.5	1.4	1.4
F.A. S2	3.2	2.5	2.4
F.A. S3	3.8	3.8	3.6

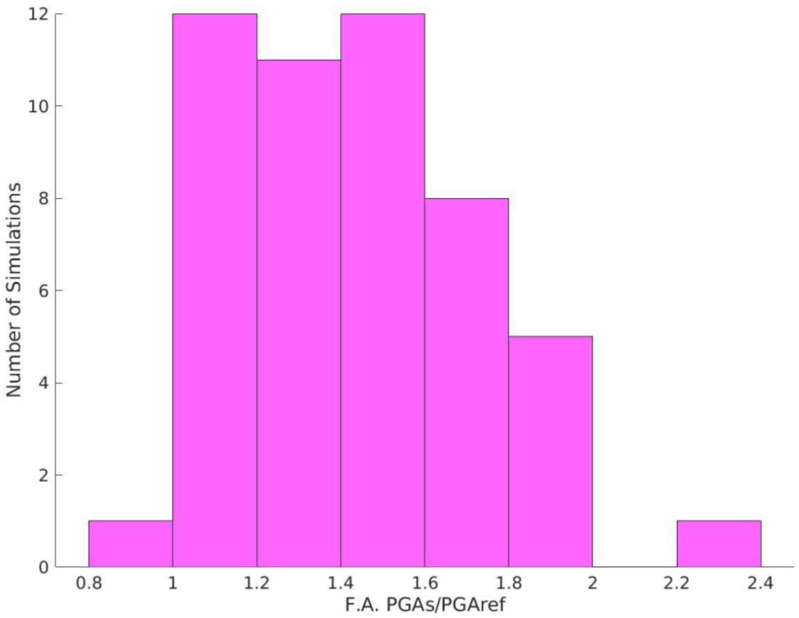
ABACUSES: STEP 3

UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 STATISTICAL ANALYSIS

CLAY

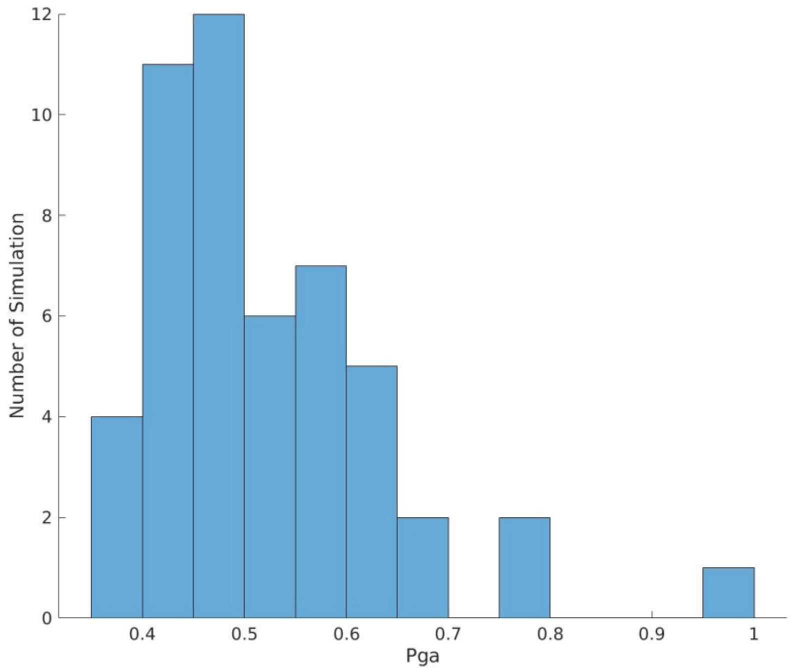


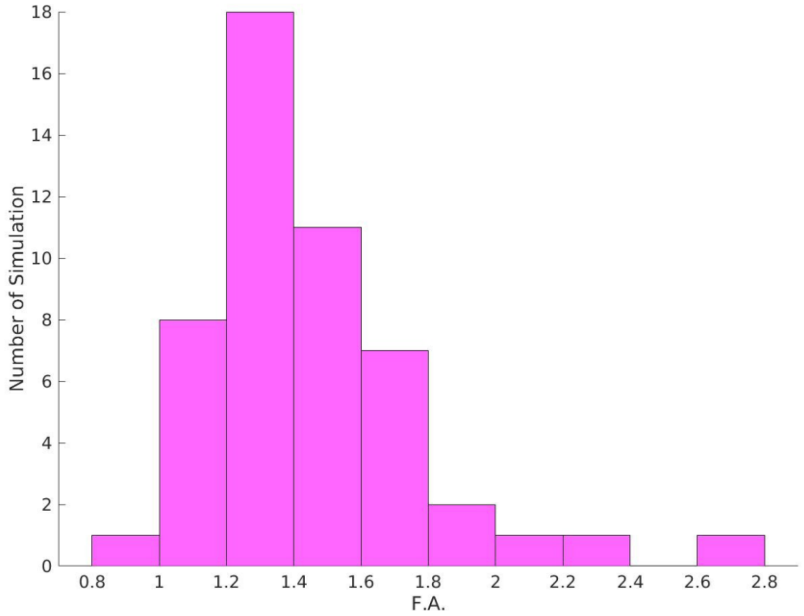


ABACUSES: STEP 3

2.1 STATISTICAL ANALYSIS

SAND

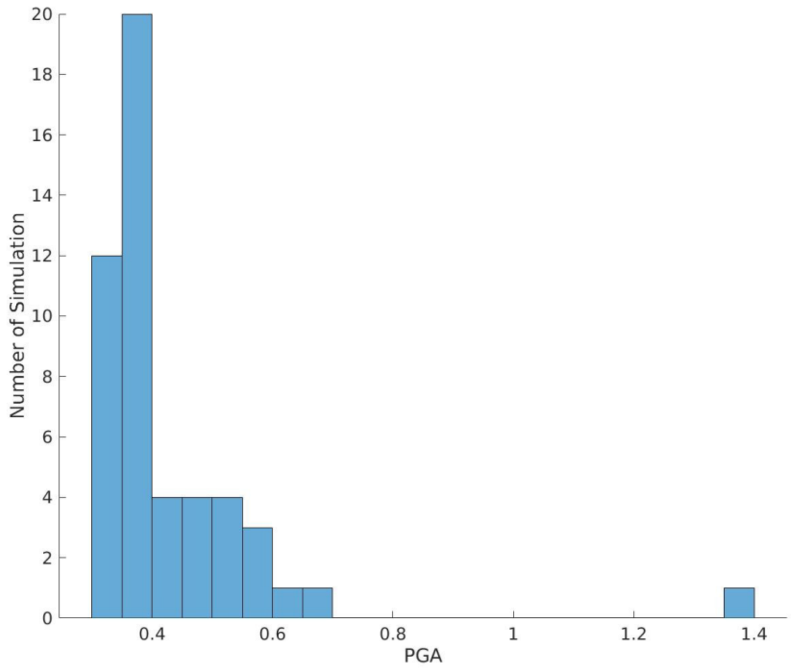


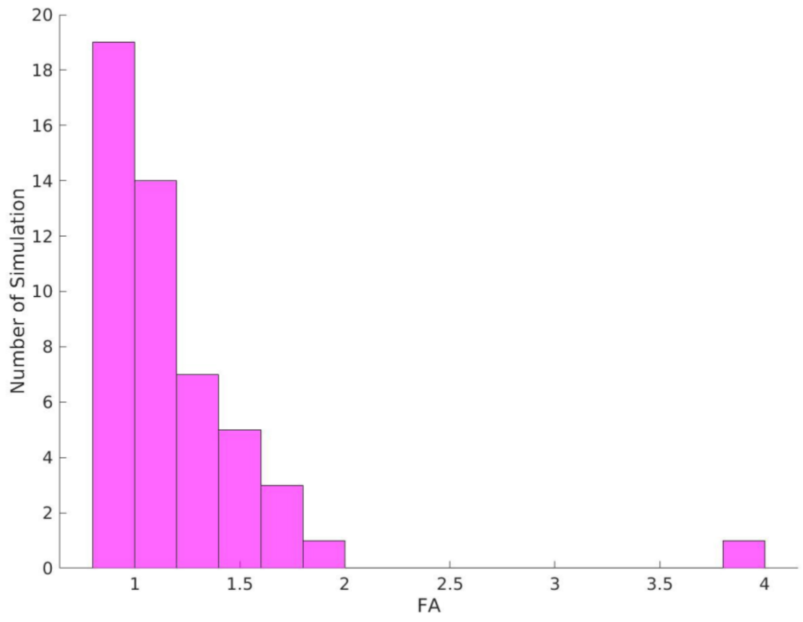


ABACUSES: STEP 3

2.1 STATISTICAL ANALYSIS

GRAVEL





ABACUSES: STEP 3

2.1 STATISTICAL ANALYSIS

CLAY

Vs30(m/s)	200	250	300
F.A. PGA	1.8	1.7	1.6
F.A. S1	1.5	1.4	1.4
F.A. S2	3.2	2.5	2.4
F.A. S3	3.8	3.8	3.6

SAND

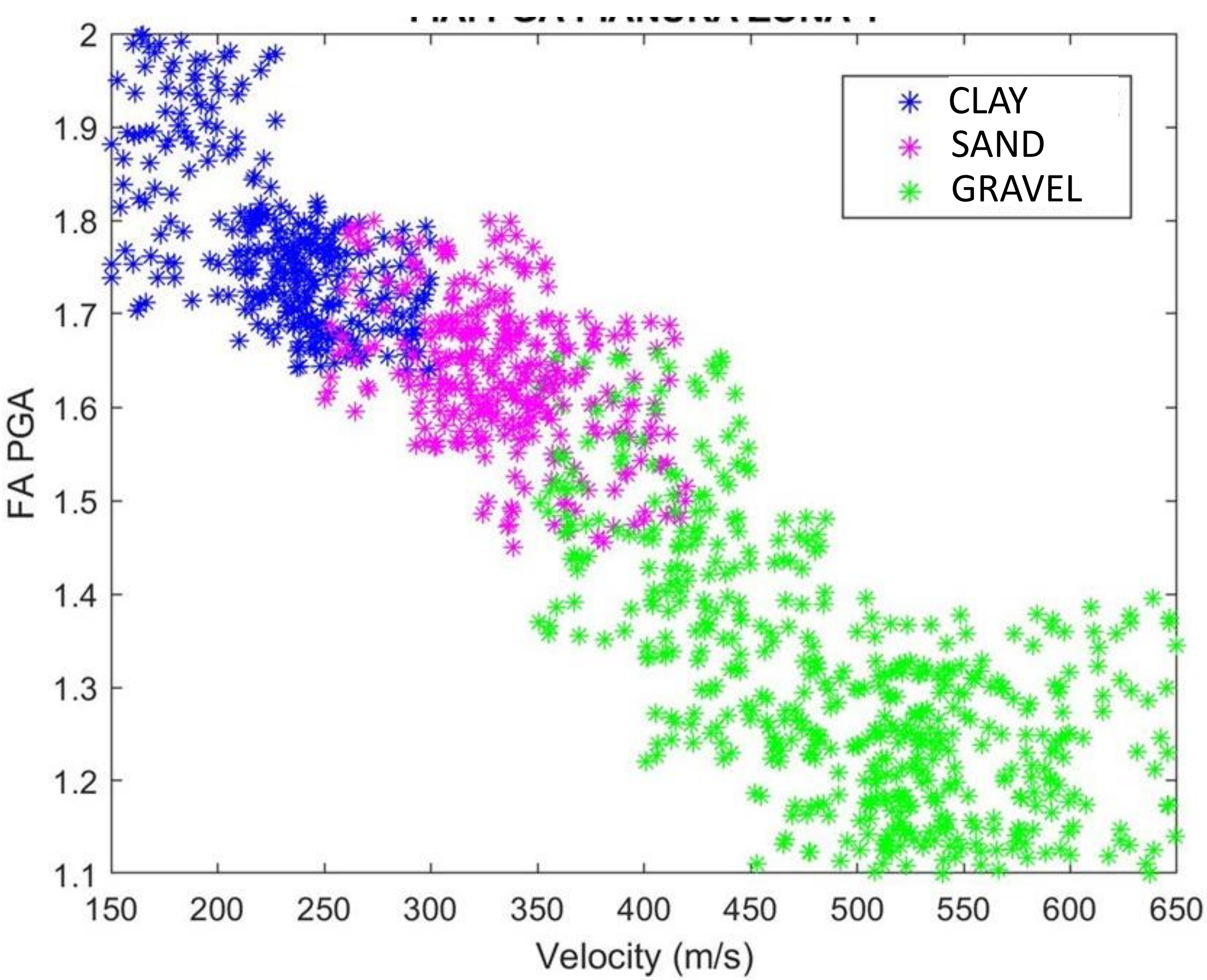
Vs30(m/s)	250	300	350
F.A. PGA	1.5	1.4	1.2
F.A. S1	1.3	1.3	1.2
F.A. S2	2.1	2.1	1.8
F.A. S3	3.5	3.5	3.1

GRAVEL

Vs30(m/s)	400	450	500	550	600
F.A. PGA	1.3	1.2	1.2	1.2	1.2
F.A. S1	1.2	1.2	1.2	1.3	1.1
F.A. S2	1.8	1.8	1.7	1.8	1.6
F.A. S3	3.1	3.1	3.1	3.1	2.8

ABACUSES: STEP 3

2.1 STATISTICAL ANALYSIS



ABACUSES: STEP 1

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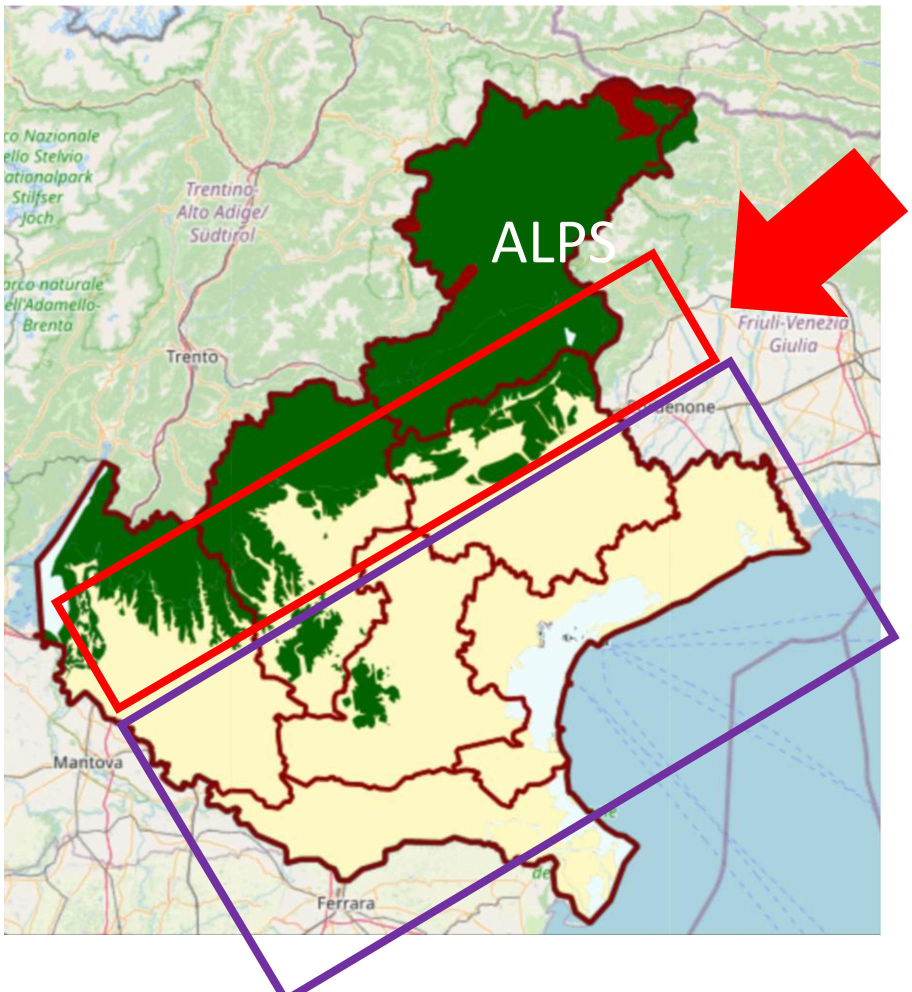
1.2 GEOPHYSICAL PARAMETERS OF THE UNITS

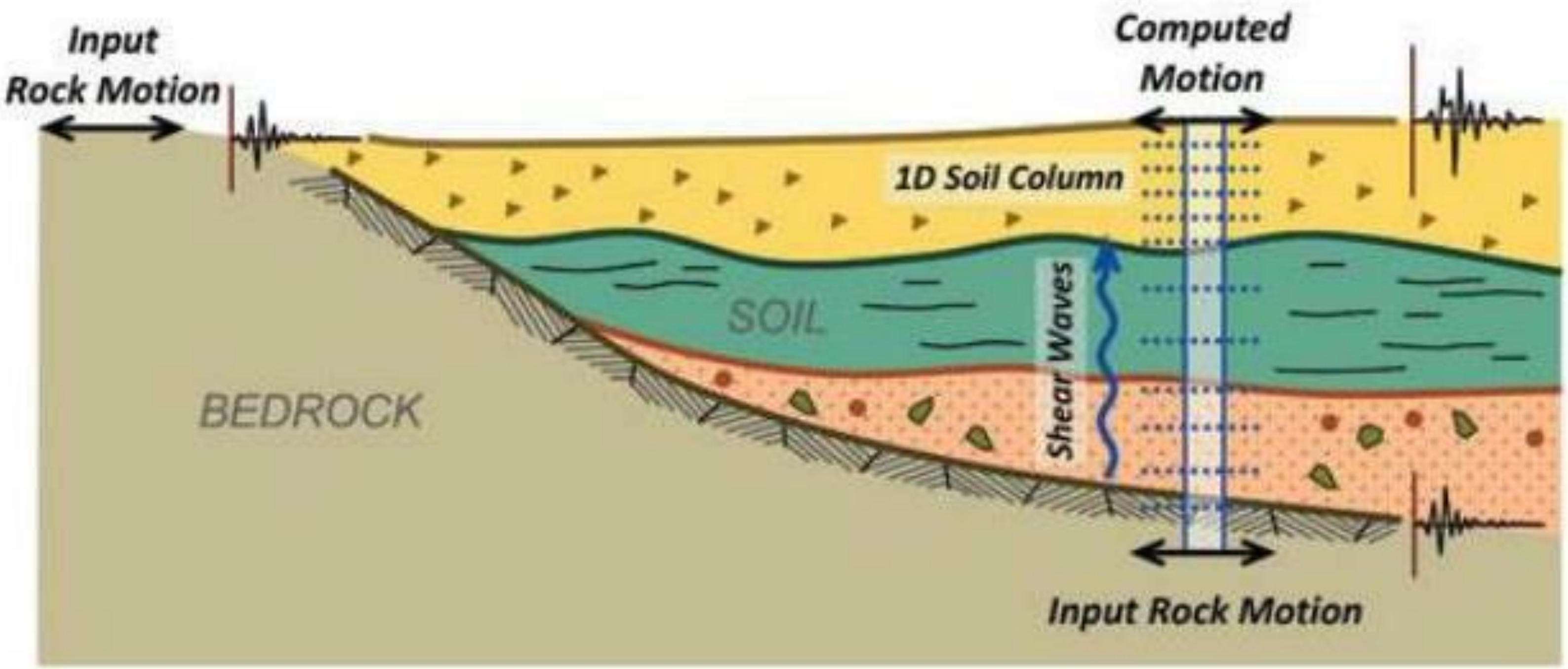


Pre-Alpine zone (variable thickness)

Alluvial Plain zone (thickness greater than 30 meters)

Pre-Alpine zone (variable thickness)

Alluvial Plain zone (thickness greater than 30 meters)



ABACUSES: STEP 3

UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 STATISTICAL ANALYSIS

Abacuses for the Pre-Alpine Zone

VsH		CLAY		SAND		GRAVEL			
H (m)	150	200	250	300	350	400	450	500	600
10	2	1.9	1.8	1.9	1.9	1.5	1.4	1.3	1.2
15	1.9	1.9	1.8	1.8	1.8	1.6	1.4	1.1	1.1
20	1.9	1.9	1.9	1.7	1.7	1.8	1.6	1.4	1.1
30		1.8	1.8	1.7	1.7	1.7	1.4	1.3	1.2
40		1.8	1.8	1.6	1.6	1.7	1.3	1.2	1.2
50		1.9	2	1.7	1.7	1.6	1.3	1.3	1.2

$$V_{S,eq} = \frac{H}{\sum_{i=1}^{N} \frac{h_i}{V_{S,i}}}$$

ABACUSES: STEP 3

UNIVERSITÀ DEGLI STUDI DI PADOVA

2.1 STATISTICAL ANALYSIS

INTENSITA' DI HOUSNER

SI (0.1 s < T < 0.5 s)

	150	200	250	300	350	400	450	500	600
10	1.9	1.8	1.6	1.4	1.3	1	1	1	1
15	2.2	2.2	2	1.7	1.3	1.1	1	1	1
20	2.3	2.2	2	2	1.7	1.5	1.3	1.3	1.2
30		2	2	1.9	1.5	1.4	1.3	1.2	1.2
40		2.6	2.6	1.7	1.4	1.4	1.2	1.2	1.1
50		2.3	2.2	1.7	1.4	1.3	1.2	1.1	1

INTENSITA' DI HOUSNER

SI (0.1 s < T < 0.5 s)

	150	200	250	300	350	400	450	500	600
10	1.9	1.8	1.6	1.4	1.3	1	1	1	1
15	2.2	2.2	2	1.7	1.3	1.1	1	1	1
20	2.3	2.2	2	2	1.7	1.5	1.3	1.3	1.2
30		2	2	1.9	1.5	1.4	1.3	1.2	1.2
40		2.6	2.6	1.7	1.4	1.4	1.2	1.2	1.1
50		2.3	2.2	1.7	1.4	1.3	1.2	1.1	1

S2 (0.4 s < T < 0.8 s)

	150	200	250	300	350	400	450	500	600
10	1	1	1	1	1	1	1	1	1
15	1.5	1.4	1.3	1.3	1	1	1	1	1
20	2.3	1.9	1.5	1.5	1.2	1.1	1	1	1
30		2.2	2.2	1.7	1.8	1.3	1.2	1	1
40		2.6	2.4	1.5	1.4	1.4	1.3	1.1	1
50		2.3	2.3	1.6	1.5	1.5	1.2	1.1	1.1

ABACUSES

STEP 1 V

- 1.1 IDENTIFY LITHO-STRATIGRAPHIC UNITS
- 1.2 GEOPHYSICAL PARAMETERS OF THE UNITS
- 1.3 SEISMIC INPUT SELECTION

STEP 2 V

- 2.1 STRATA SOFTWARE
- 2.2 AMPLIFICATION FACTOR ESTIMATIONS
- 2.2 RANDOM GENERATION OF Vs PROFILES

STEP 3 V

- 3.1 ABACUSES REALIZATION