The Abdus Salam International Centre for Theoretical Physics

2016

Joint ICTP/IAEA Advanced Workshop on Earthquake Engineering for Nuclear Facilities

30 November - 4 December, 2009

Seismic microzoning: the example of Napoli

(Presentation)

NUNZIATA D'Elia Concettina

Universita' degli Studi di Napoli Frederico II

Geofisica & Vulcanologia

Largo S. Marcellino 10 80138

Napoli

ITALY

Seismic microzoning: the example of Napoli

C. Nunziata

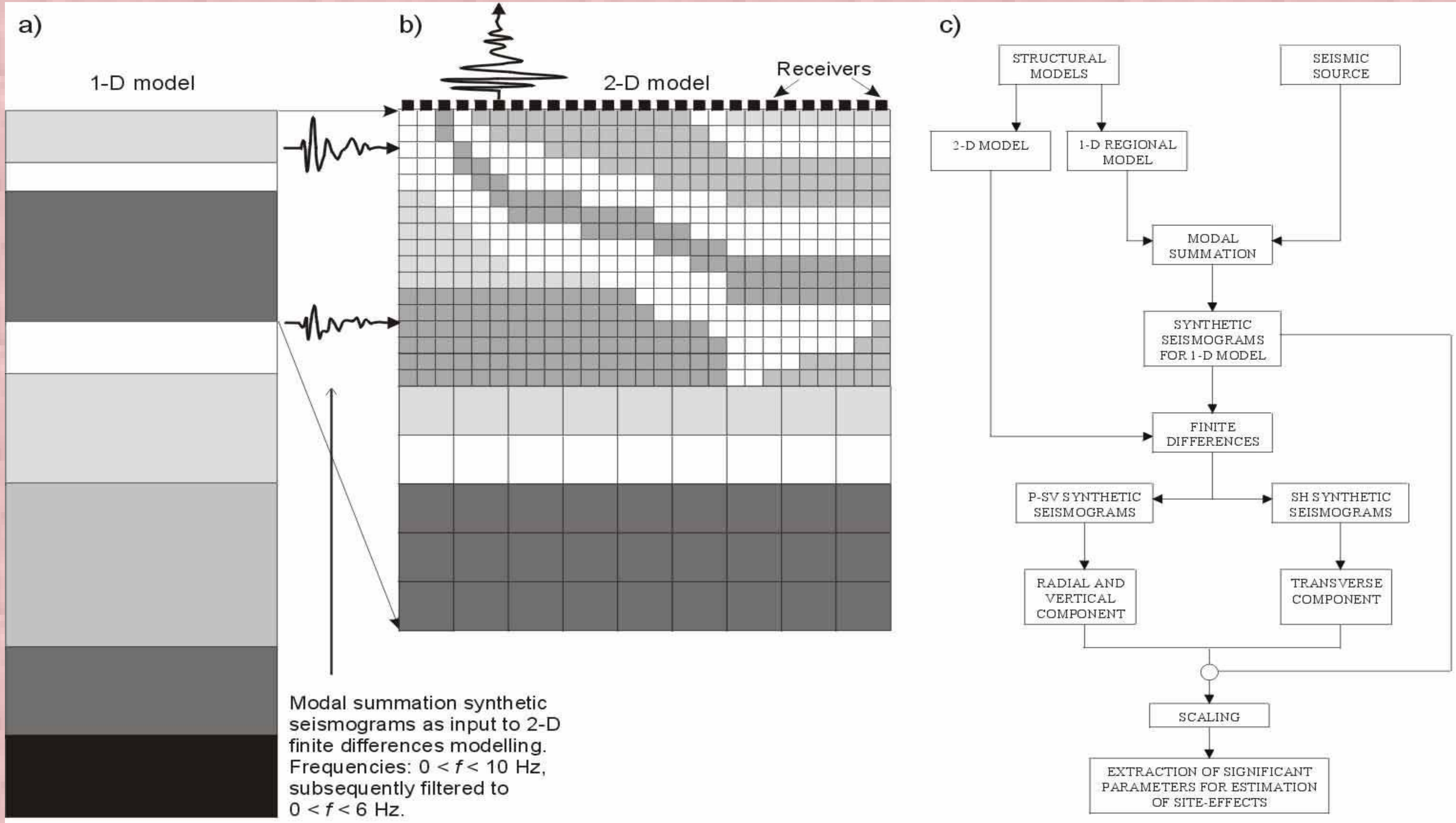
Dipartimento di Scienze della Terra
Università degli Studi di Napoli Federico II

Neo-Deterministic approach for the ***seismic microzoning of Napoli*** in the framework of the **UNESCO-IUGS-IGCP** project 414 "Seismic Ground Motion in Large Urban Areas" (Algiers, Alexandria, Beijing, Bucharest, Cairo, Delhi, Napoli, Santiago de Cuba, Sofia, Thessaloniki,Zagreb)

and

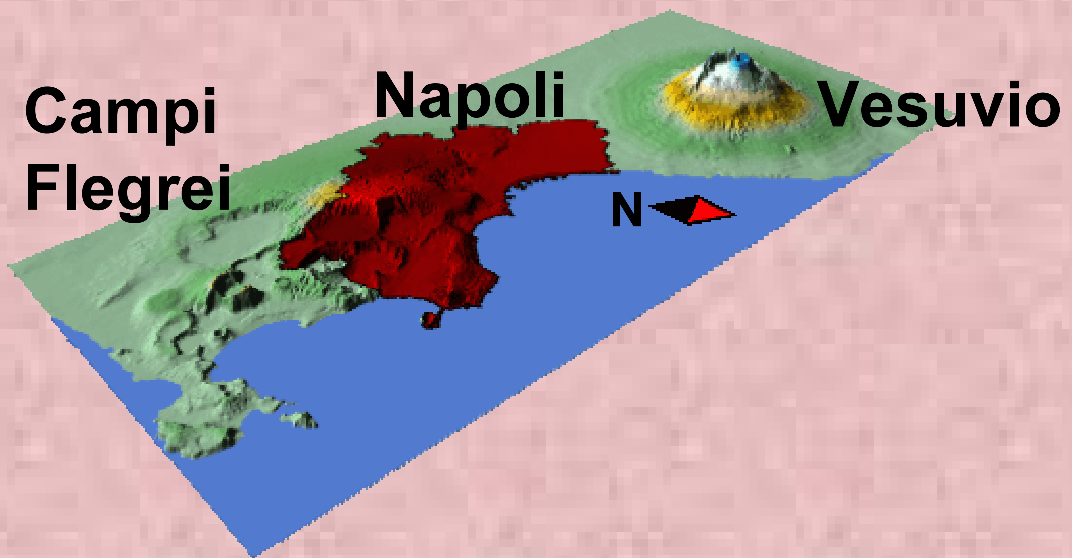
PON Petit-Osa Project

Hybrid Method: Mode Summation+Finite Differences



For tectonic events (distance > 50 km), source can be assumed point and scaled to extended one by using the relatively simple spectral scaling laws by Gusev (1983). Site amplification effects are estimated in terms of spectral amplification, defined as the response spectrum at a site in the laterally heterogeneous (2D) structural model, normalized to the response spectrum computed for the (1-D) average reference bedrok model.

SEISMIC MICROZONING THE EXAMPLE OF NAPOLI

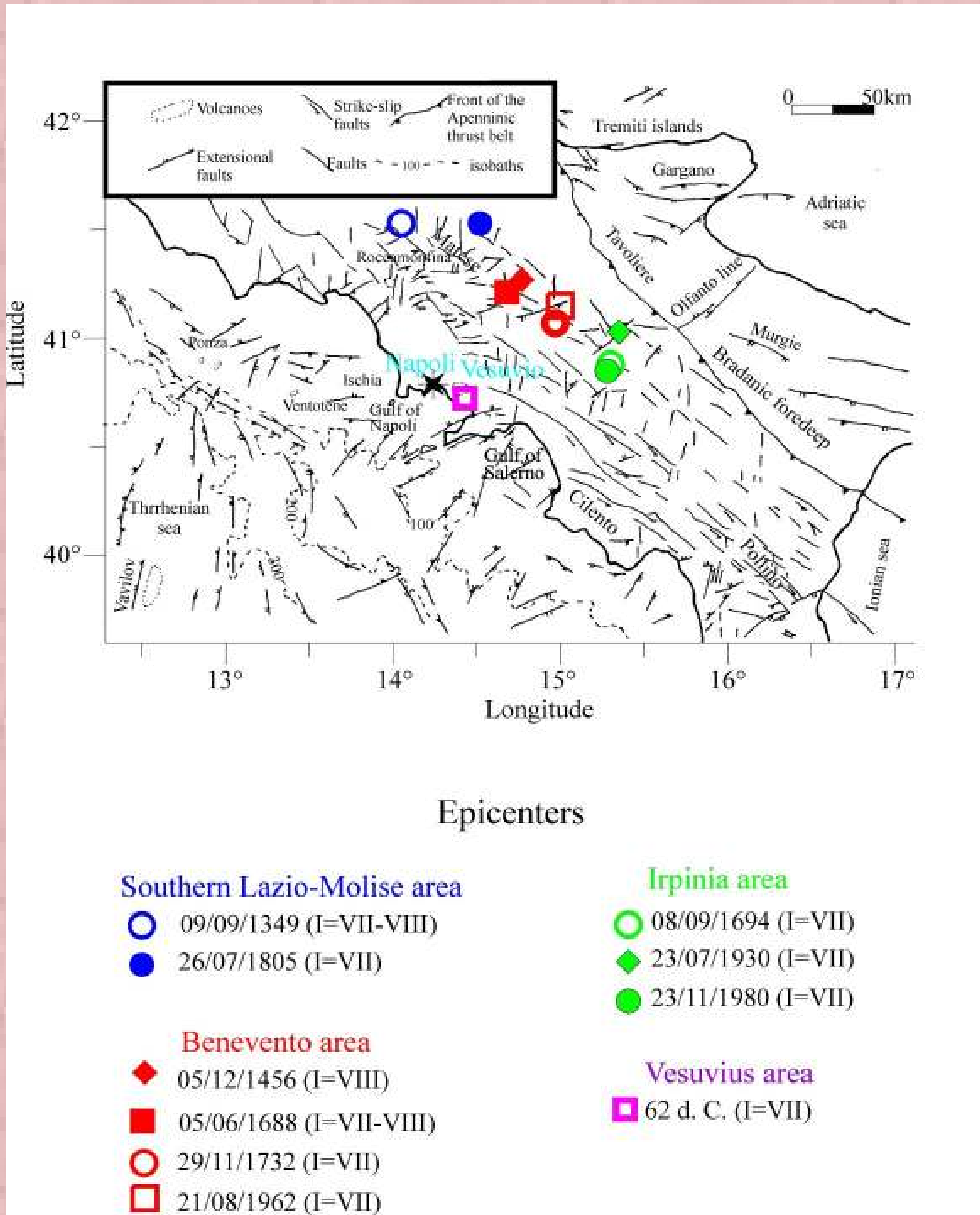


Microzoning

(including lateral heterogeneities)

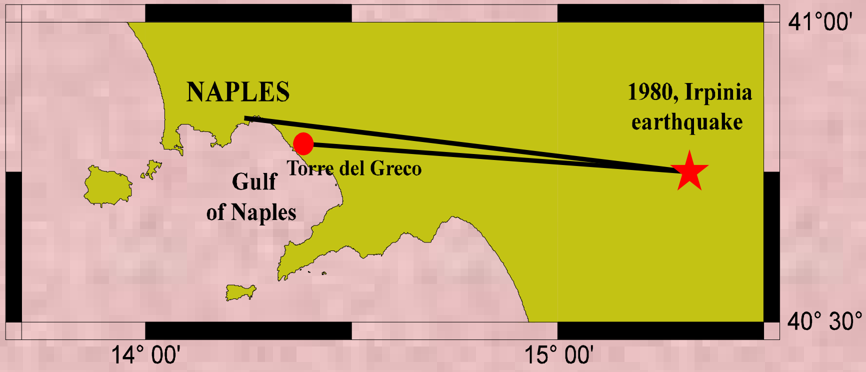
- Historical seismicity and instrumental recordings
- Reconstruction of the geological setting
- Definition of shear wave velocity profiles
- Realistic modelling of ground motion

Historical Strong Earthquakes In Napoli I=VII, VIII (MCS)

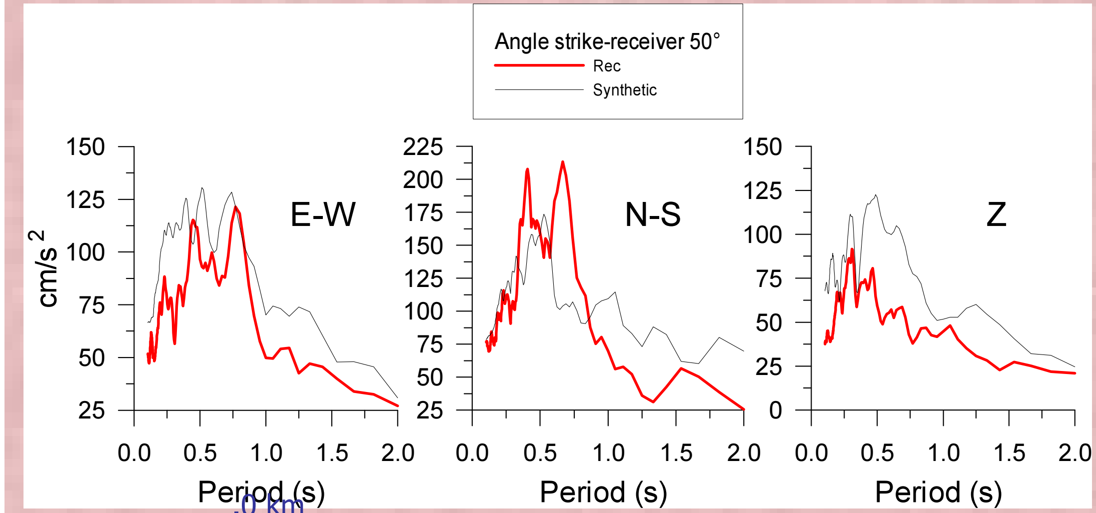


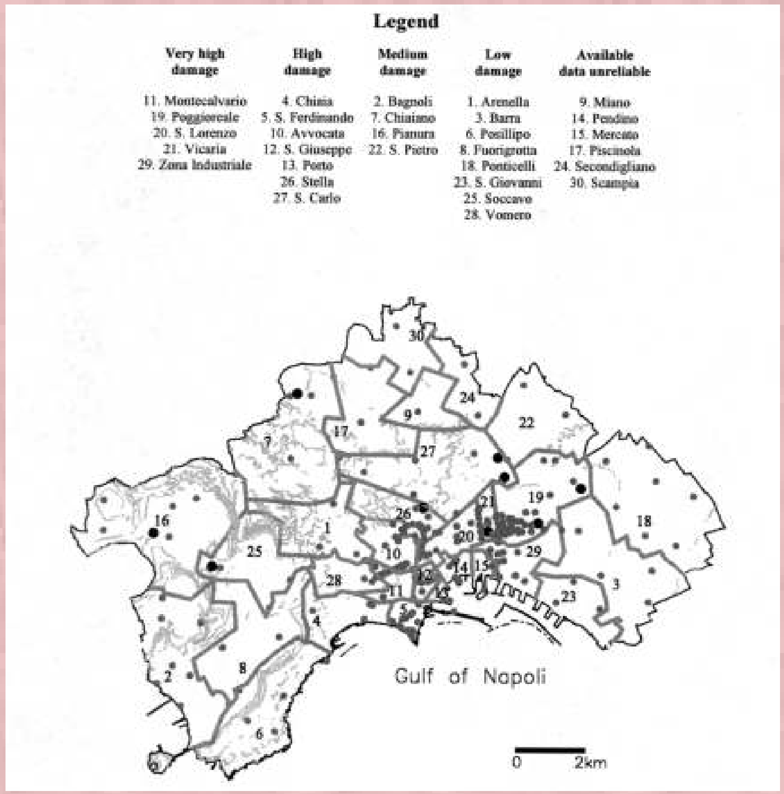
FIRST INSTRUMENTAL RECORDING

The last strong event, **the November 23, 1980 (M_S=6.9)**, was recorded (amax=0.06g) at the seismic station Torre del Greco.



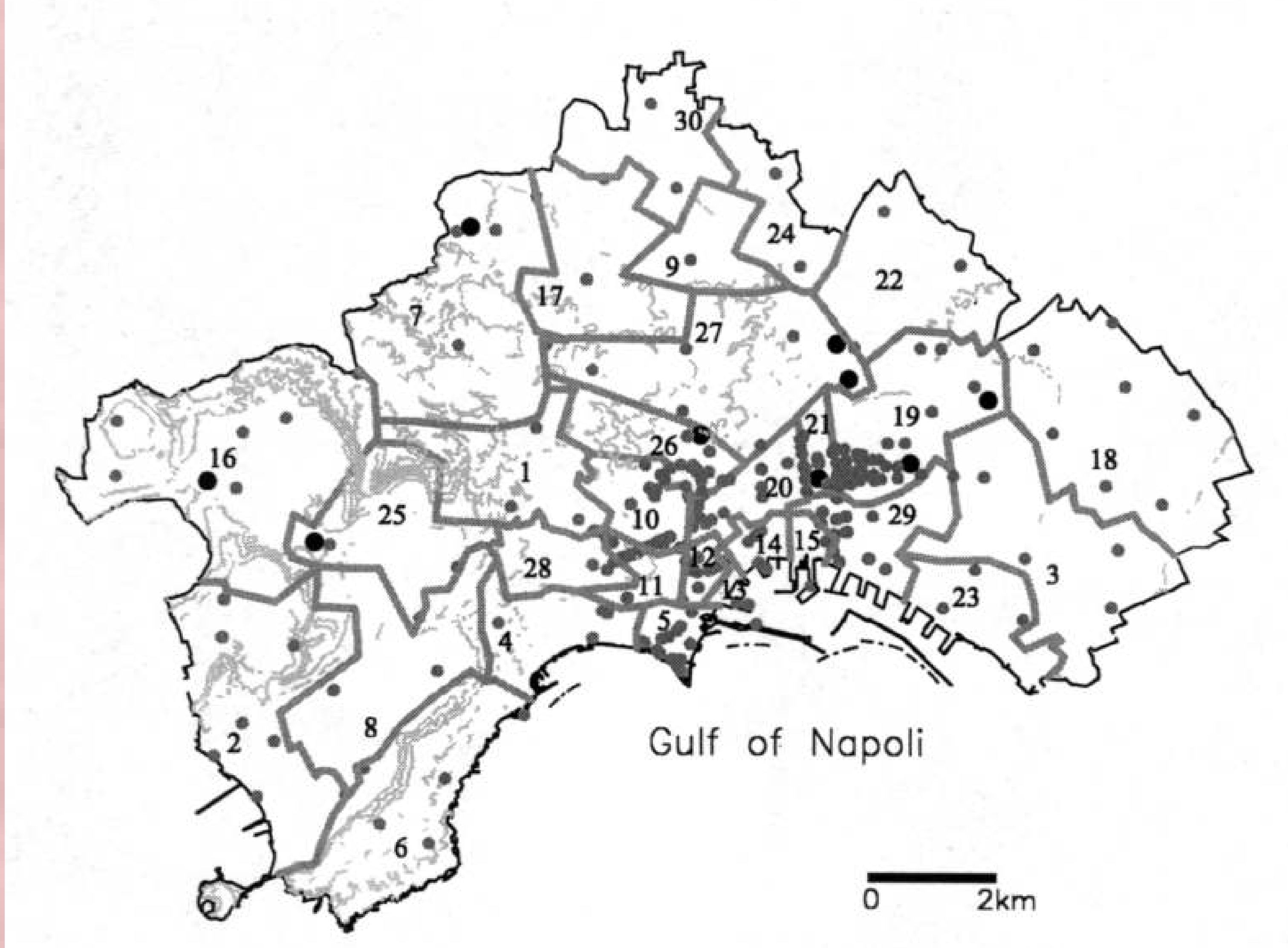
Good comparison between synthetic and observed signals is obtained for a source mechanism dip 65°, rake 270°, strike 315° and depth of 7.0 km



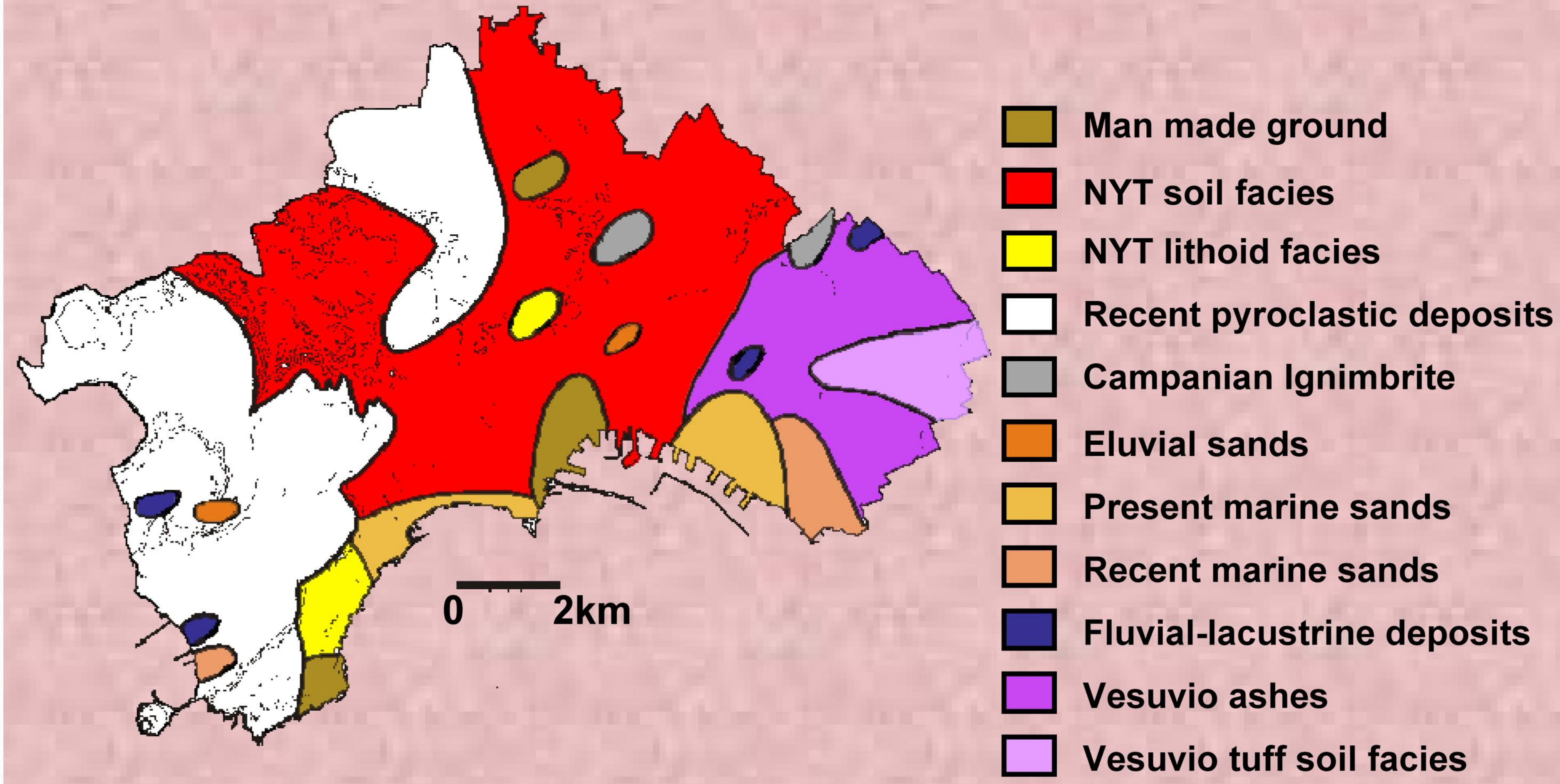


Damage distribution in *Napoli* caused by the 1980 Irpinia earthquake

Reconstruction of the geological setting

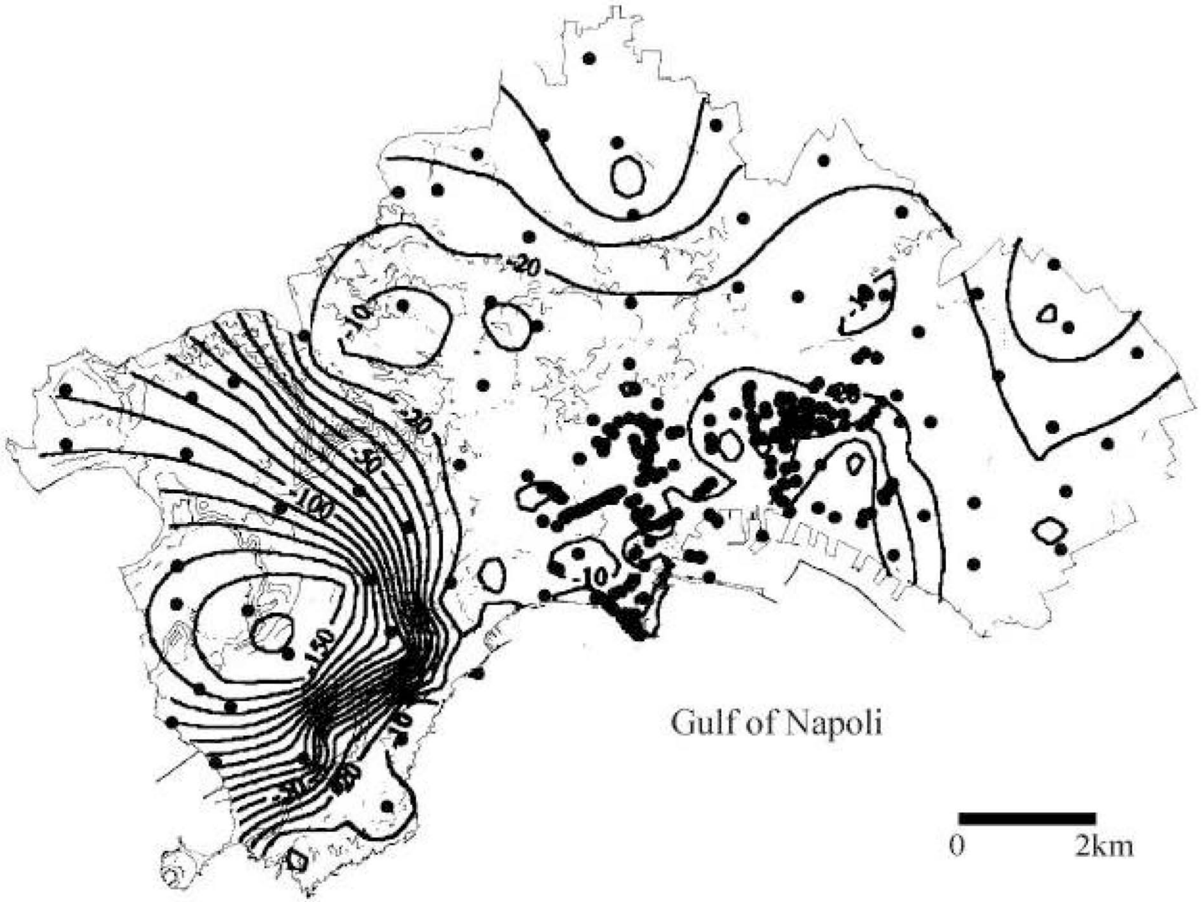


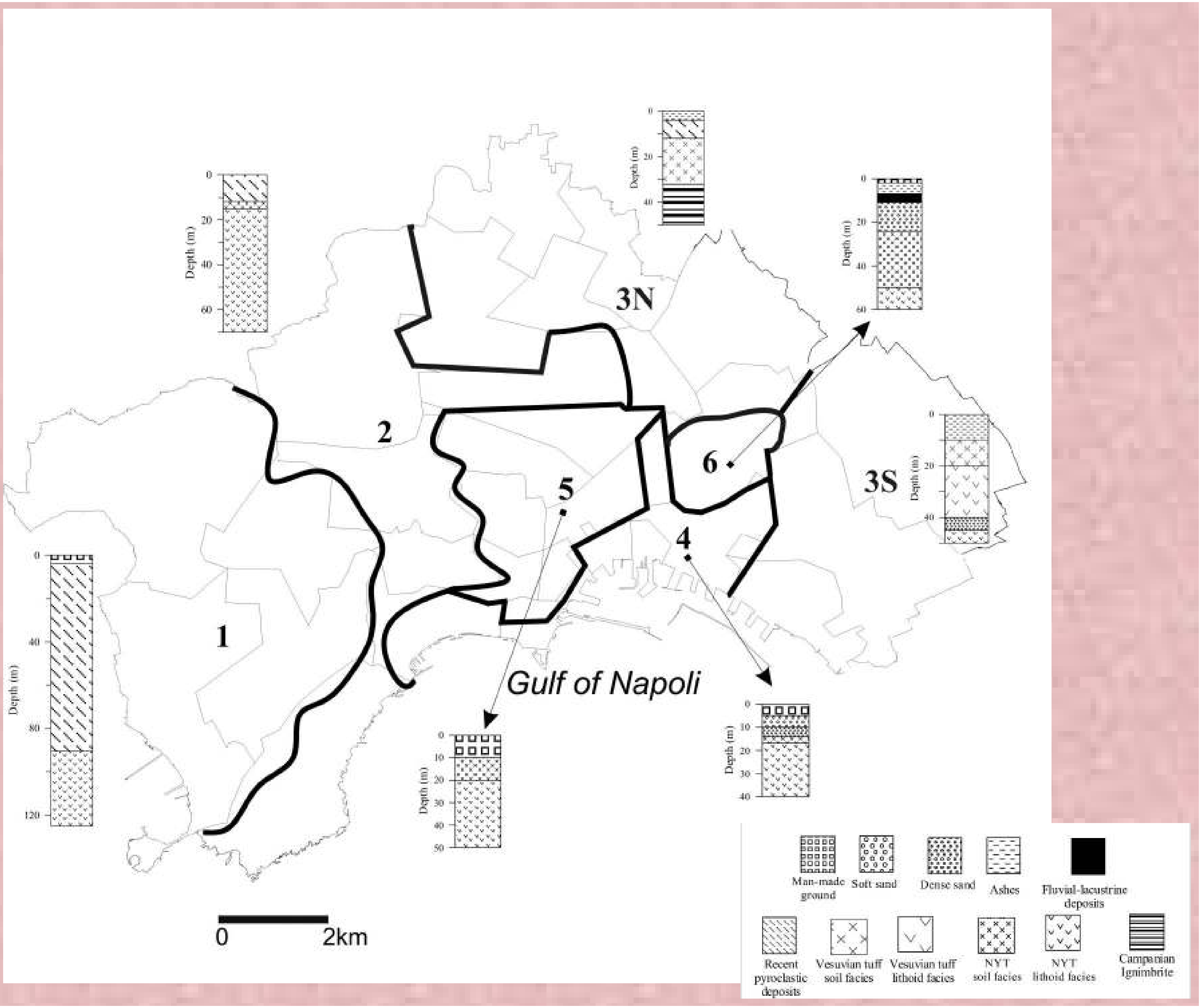
Volcanological map of Napoli at 10m of depth from ground surface



Volcanological map of Napoli at 10m of depth from ground surface

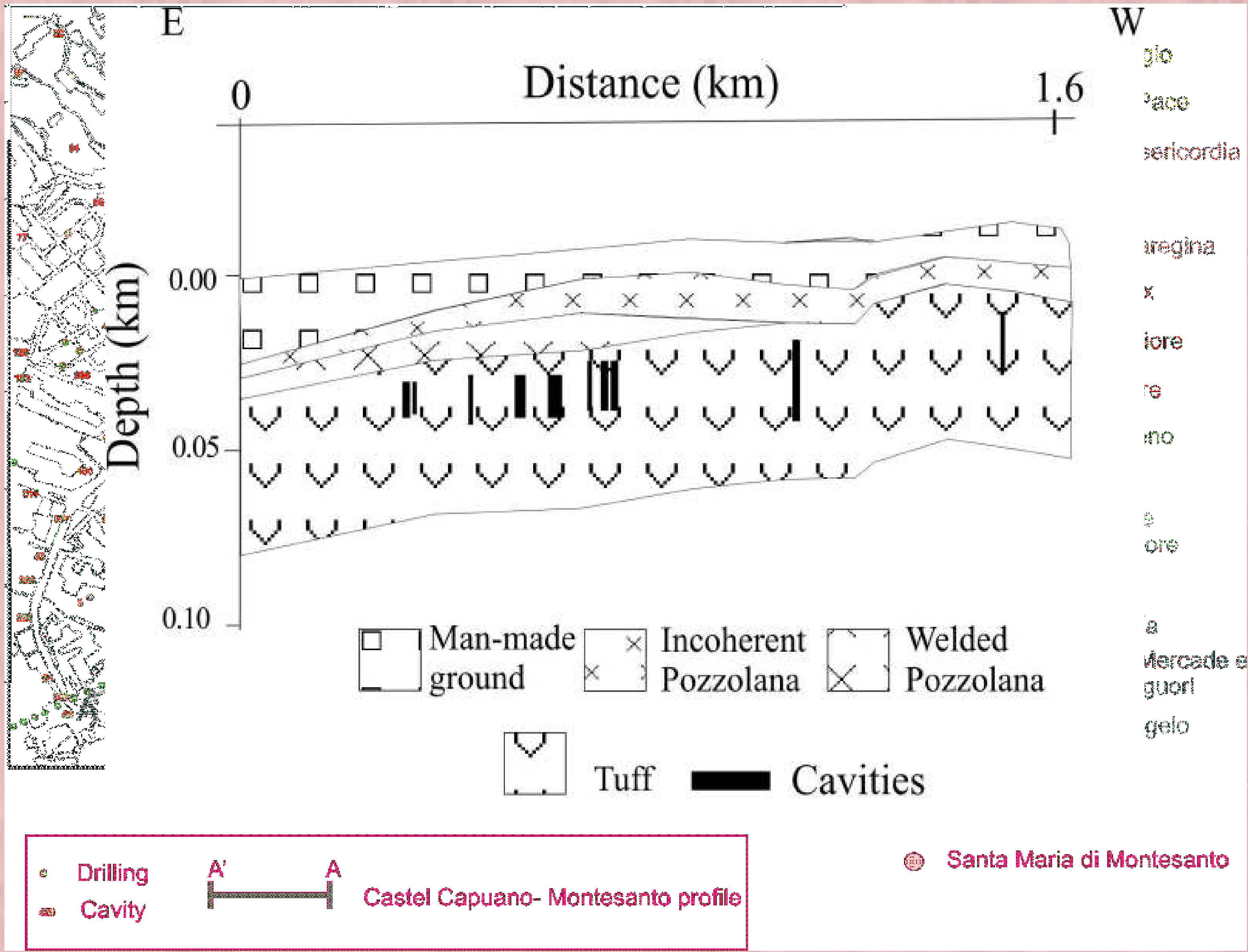
Isobaths of the lithoid tuff horizon (m)





1
2
3N
3S
4
5
6
Gulf of Napoli
0
2km
Depth (m)
Man-made ground
Soft sand
Dense sand
Ashes
Fluvial-lacustrine deposits
Recent pyroclastic deposits
Vesuvian tuff soil facies
Vesuvian tuff lithoid facies
NYT soil facies
NYT lithoid facies
Campanian Ignimbrite

Historical centre



Definition of shear wave velocity profiles with depth

METHODS

SURFACE MEASUREMENTS

BODY WAVES
Seismic Refraction Surveys

SURFACE WAVES

Phase velocities

SASW
MASW
f-k
REMI

Group velocities

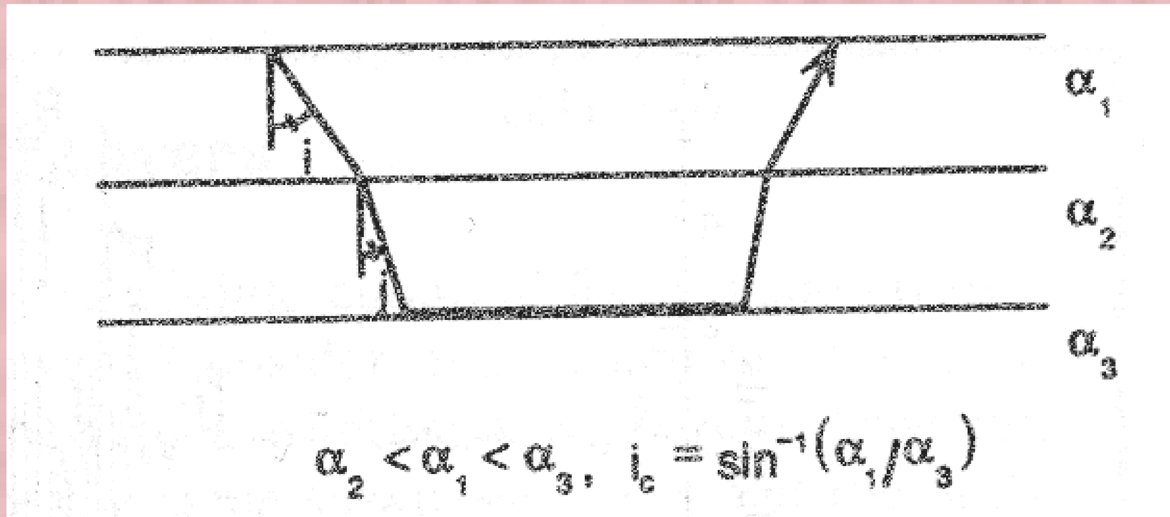
FTAN

HOLE MEASUREMENTS

Down-hole test
Cross-hole test

Seismic Refraction Surveys

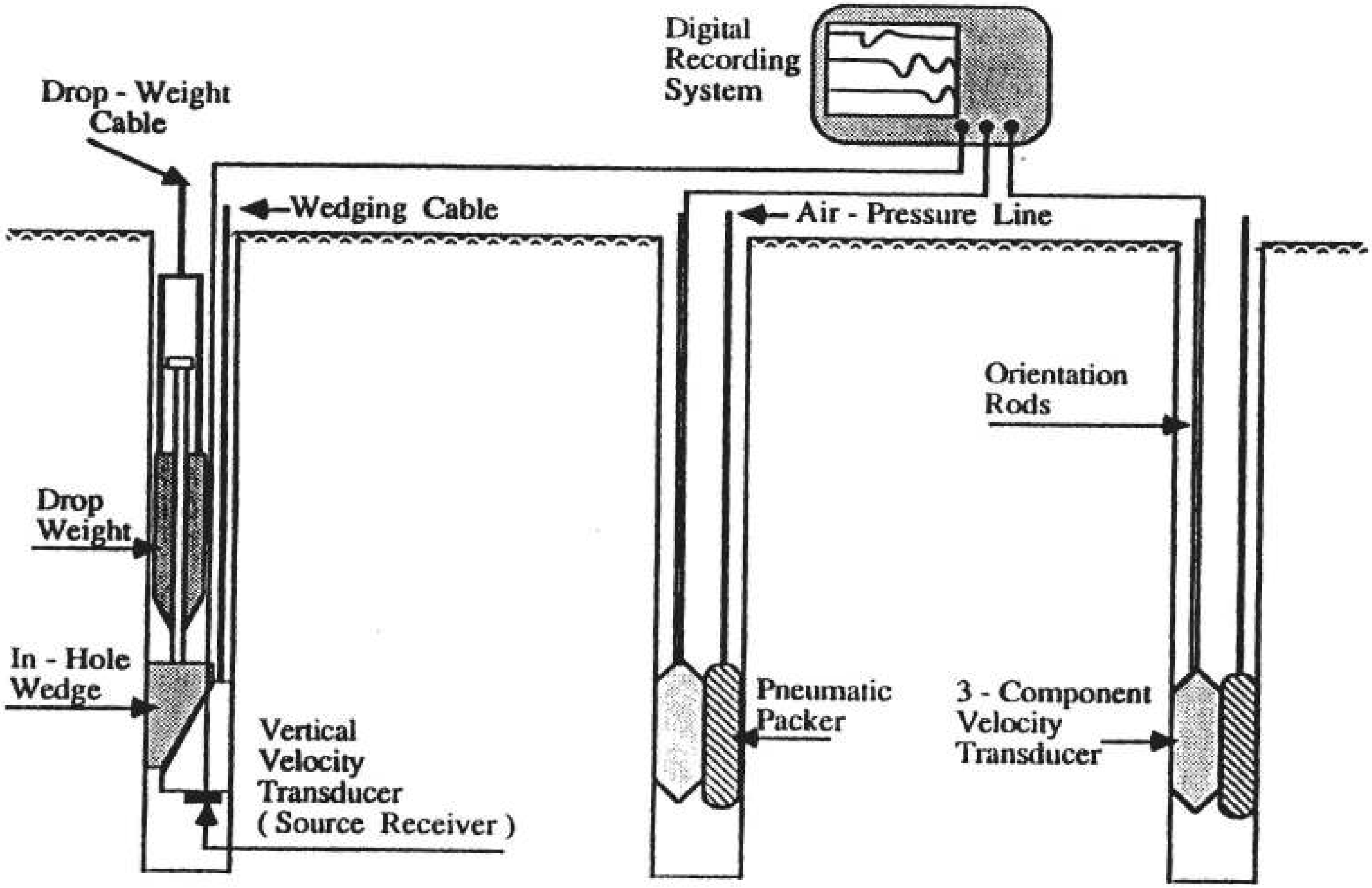
Limits



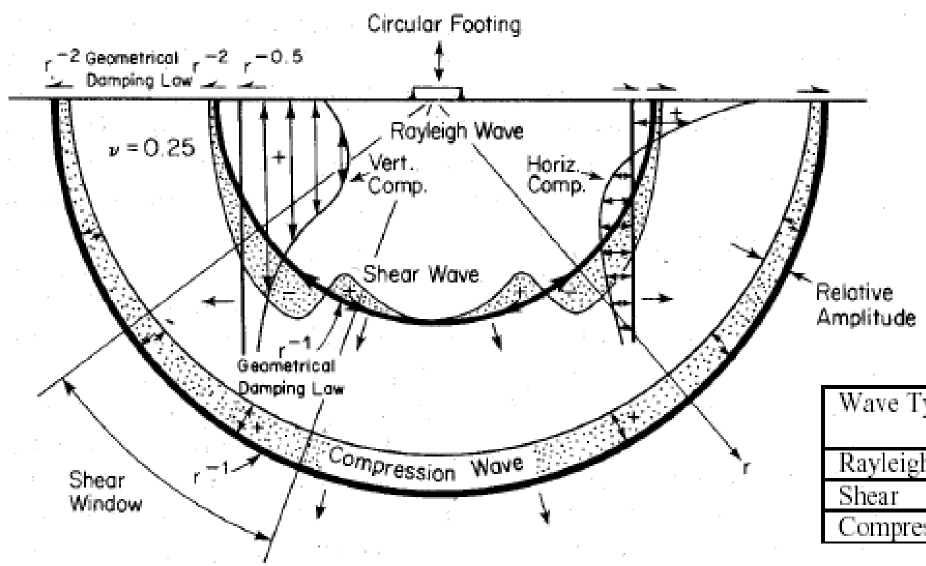
Blind layer

Generation of shear waves

Cross-hole test is the best for detailed V_S profiles but 3 wells are requested



Schematic Diagram of Crosshole Testing with Associated Equipment



Wave Type	Percent of Total Energy
Rayleigh	67
Shear	26
Compression	7

1. Percentage of Rayleigh waves (67%) generated higher than that of body waves P (7%) and S (26%)

2. Lower attenuation of *surface waves* $\sqrt{r}$

Surface waves are particularly suitable for highly attenuating soils and noisy environments

SURFACE WAVES

$$c(\omega) = \frac{\omega}{k(\omega)} \qquad \mathrm{U}(\omega) = \frac{1}{\frac{dk(\omega)}{d\omega}}$$

$$U(\omega) = \frac{x}{\left[t_0 + \frac{d\phi_R(\omega)}{d\omega} - \left(\frac{d\phi_S(\omega)}{d\omega}\right)\right]} \qquad c(\omega) = \frac{x}{\left[t_0 + \frac{\phi_R(\omega) - \phi_S(\omega) \pm 2\pi N}{\omega}\right]}$$

t_o the delay of the analyzed signal relative to the origin time

ϕ_R ϕ_S phase at the receiver and source N an integer number

Two station method

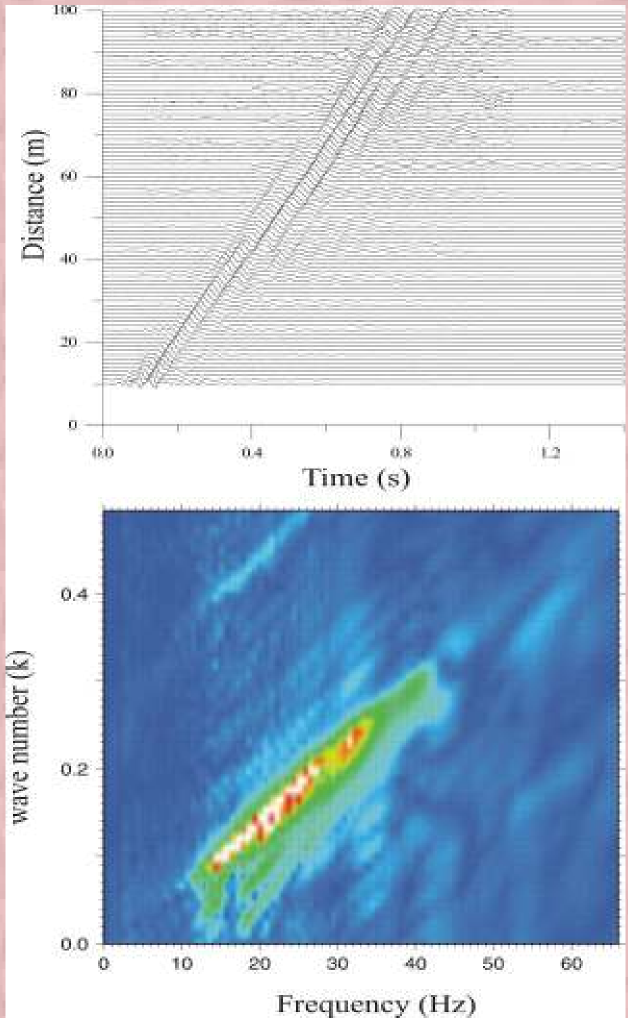
$$c(\omega) = \frac{dx}{\left[dt_0 + \frac{d\phi_R(\omega) \pm 2\pi dN}{\omega}\right]}$$

SASW

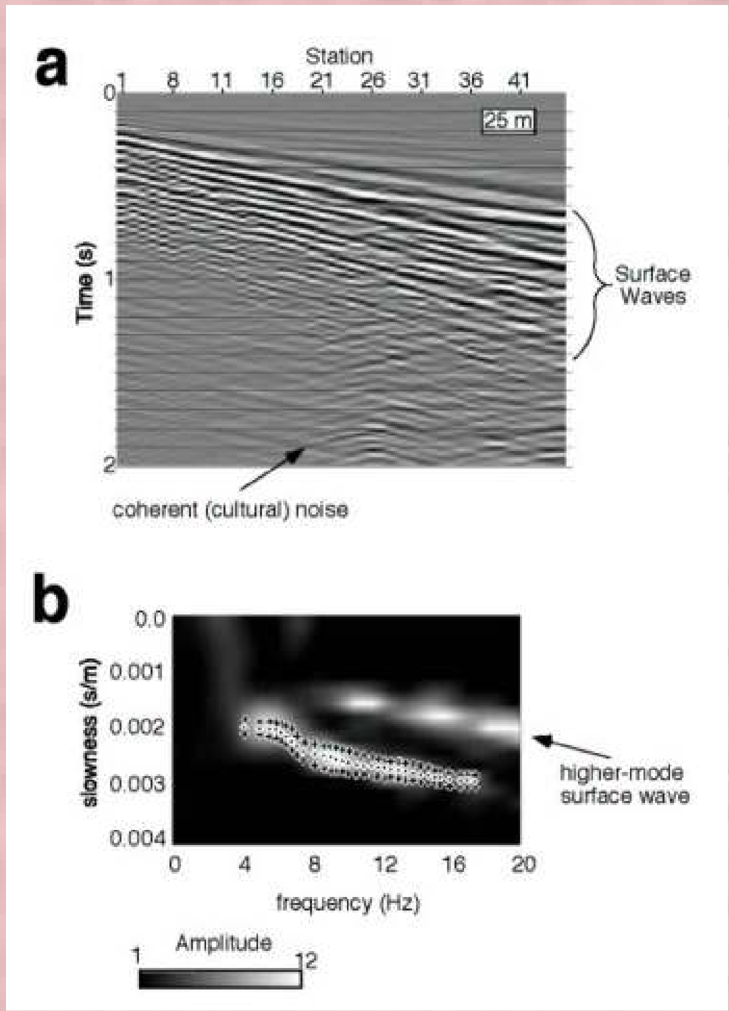
(Nazarian and Stokoe, 1984)

Multichannel spread

f-k method
(two-dimensional Fourier spectrum)
(Horike, 1985)

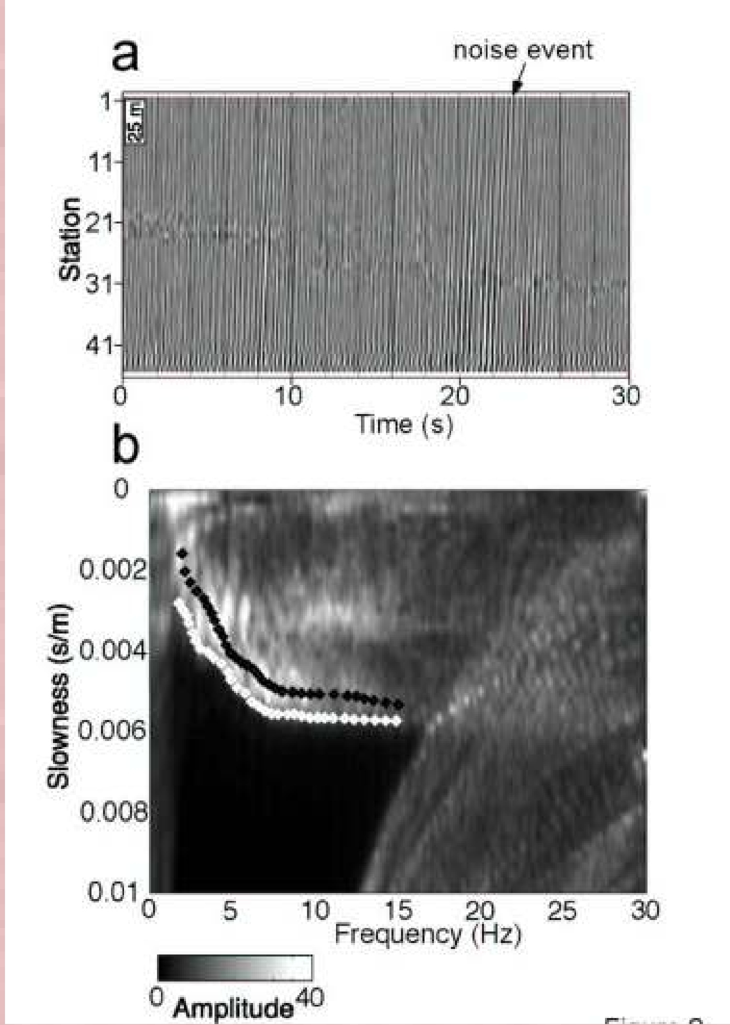


MASW
(Multichannel Analysis of Surface Waves)
(velocity spectral p-f analysis) (Park et al., 1999)



ReMi (Refraction Microtremor method) (Louie, 2001)

(velocity spectral p-f analysis)



Since it is not possible to recognize noise arrival azimuth, apparent phase velocities picked on spectral peaks may be artificially high.

Louie (2001) recommends to select at least two extremal dispersion curves: one at low phase velocity along the threshold where the spectra depart from the incoherent noise and the other one at high phase velocity along the spectral peaks.

For **microzoning studies**,

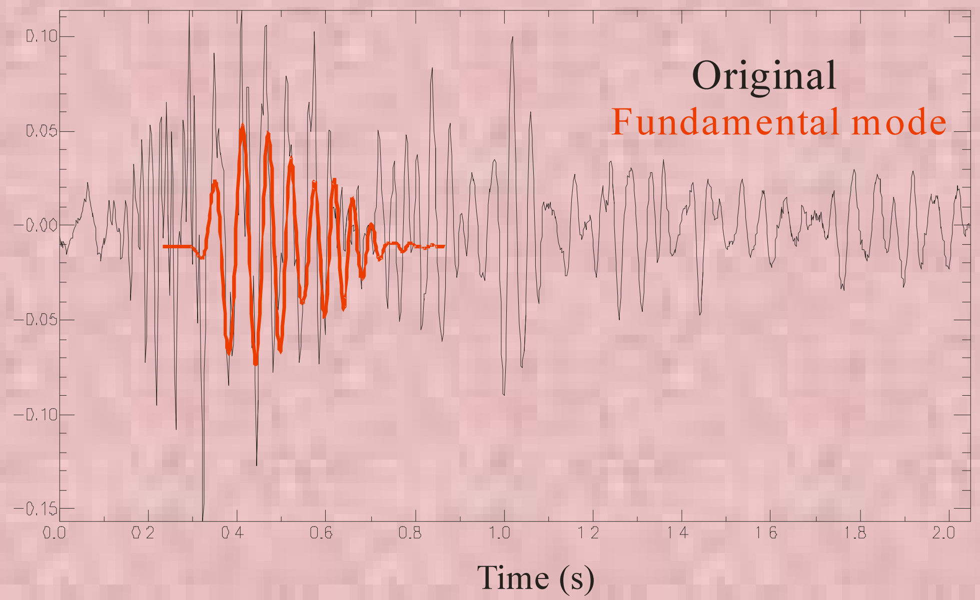
mostly in urban areas,

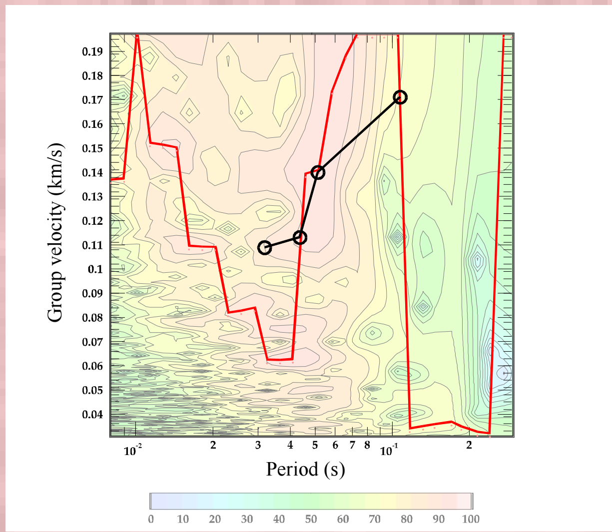
detailed Vs depth profiles can be obtained from non linear inversion of group velocities of Rayleigh wave fundamental mode with

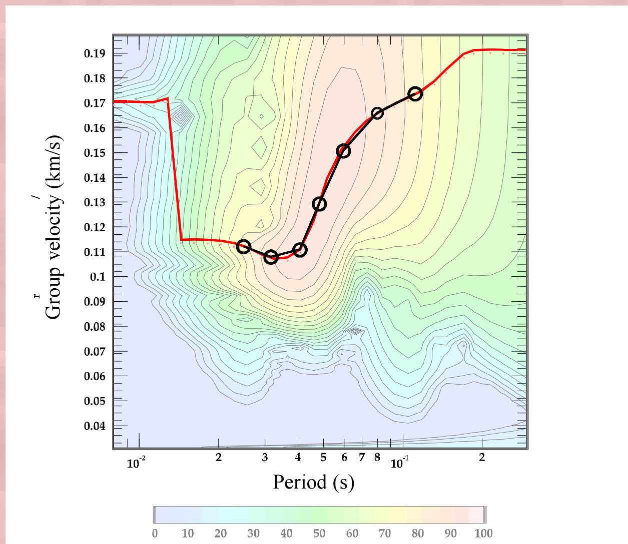
FTAN method

(Frequency-Time Analysis)

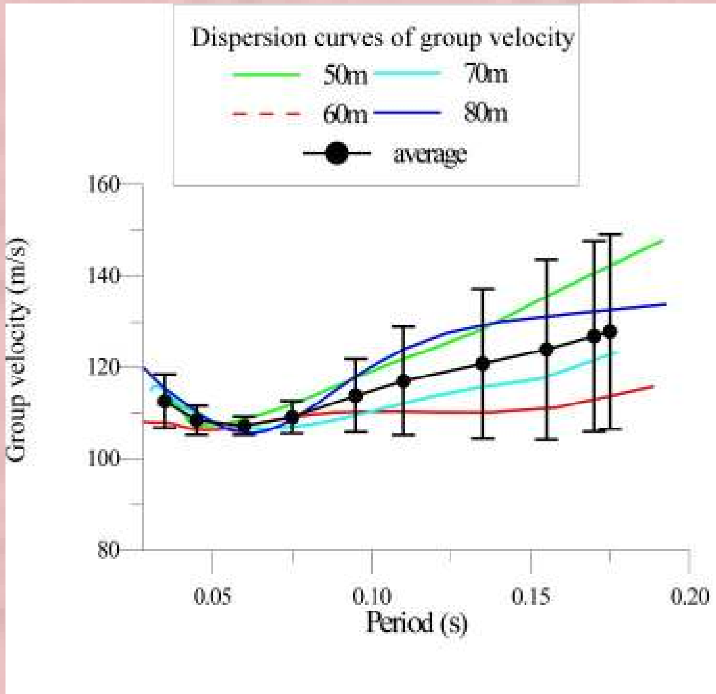
One receiver



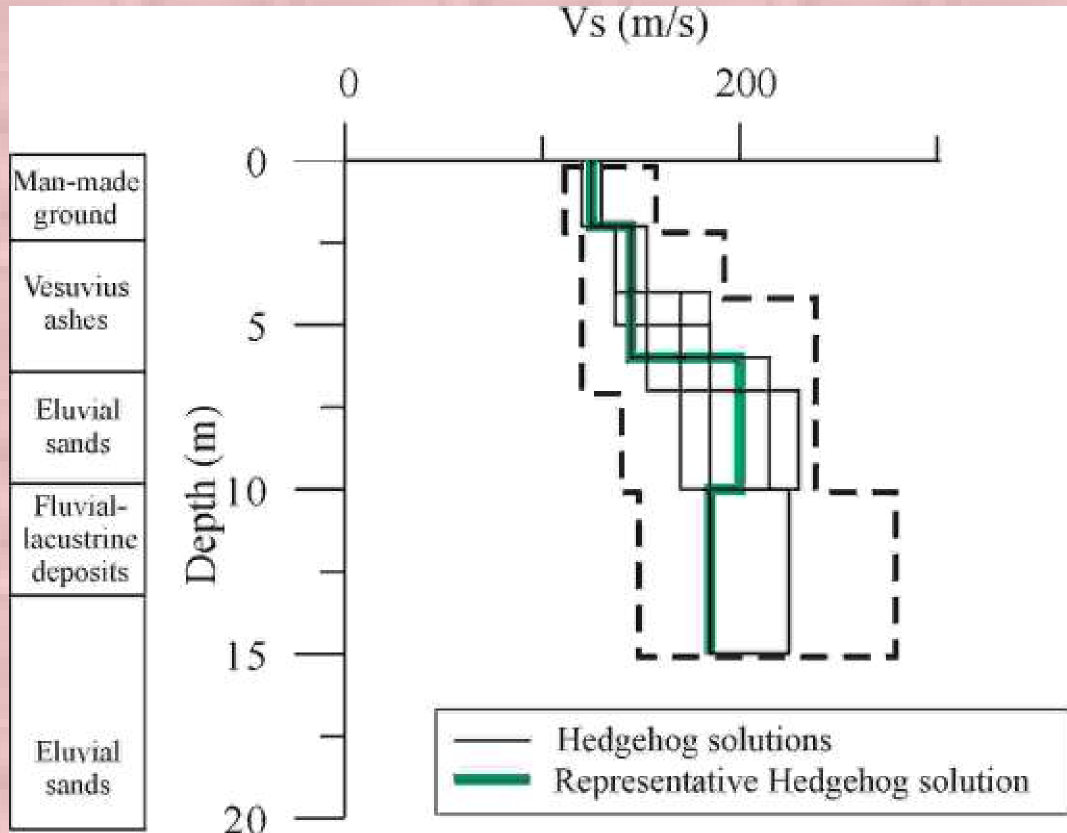




FTAN and non linear inversion of Rayleigh wave group velocity dispersion curve



(a)

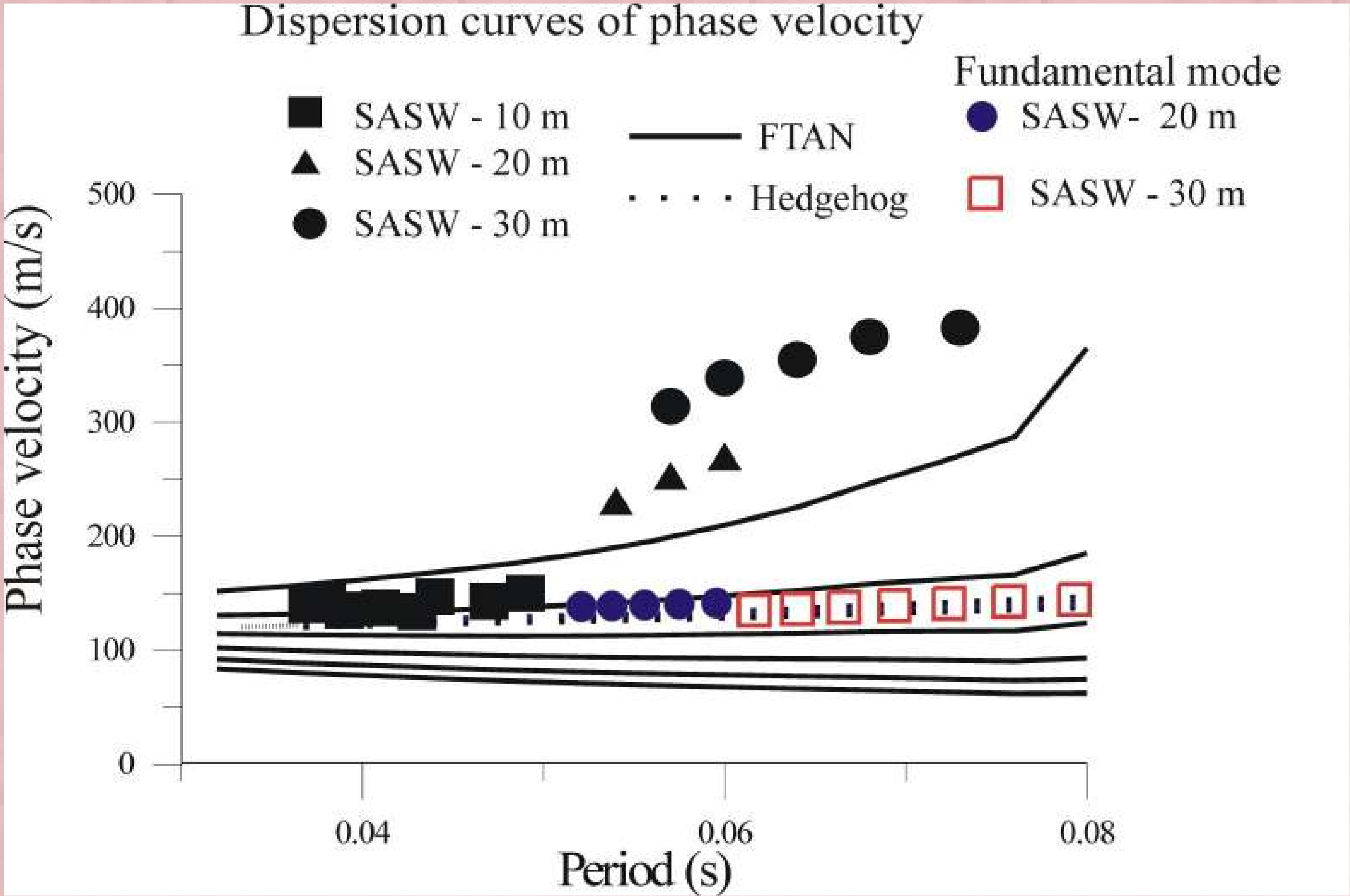


(b)

(a) Dispersion curves of group velocity relative to receivers with 50, 60, 70, and 80m offsets at Napoli. (b) Shear wave velocity models: the dashed line indicates the searched part of the parameter's space, while the accepted models are represented by the solid lines (*Nunziata* et al., 1999).

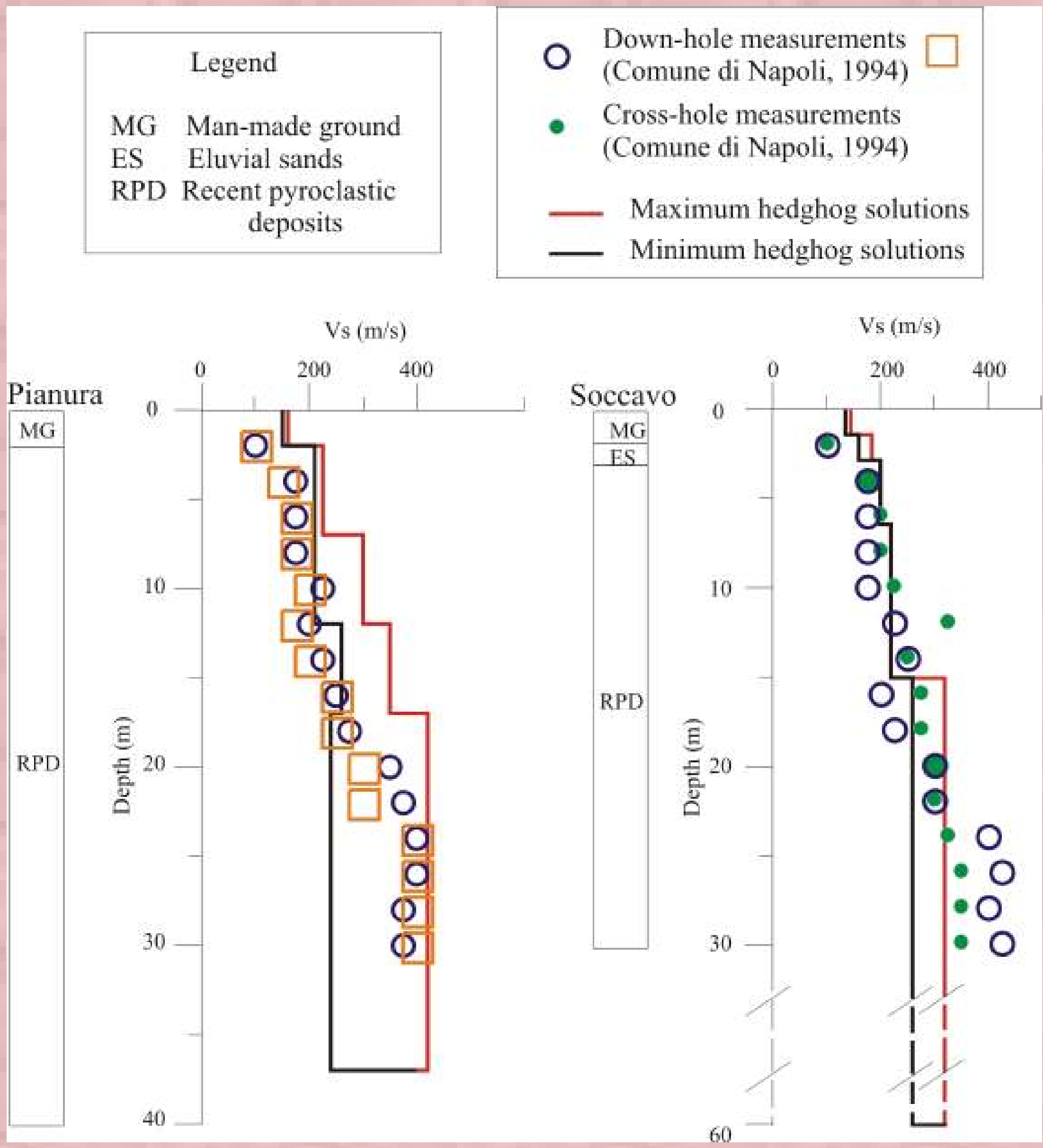
FTAN
Measurements in different soils

FTAN and SASW methods

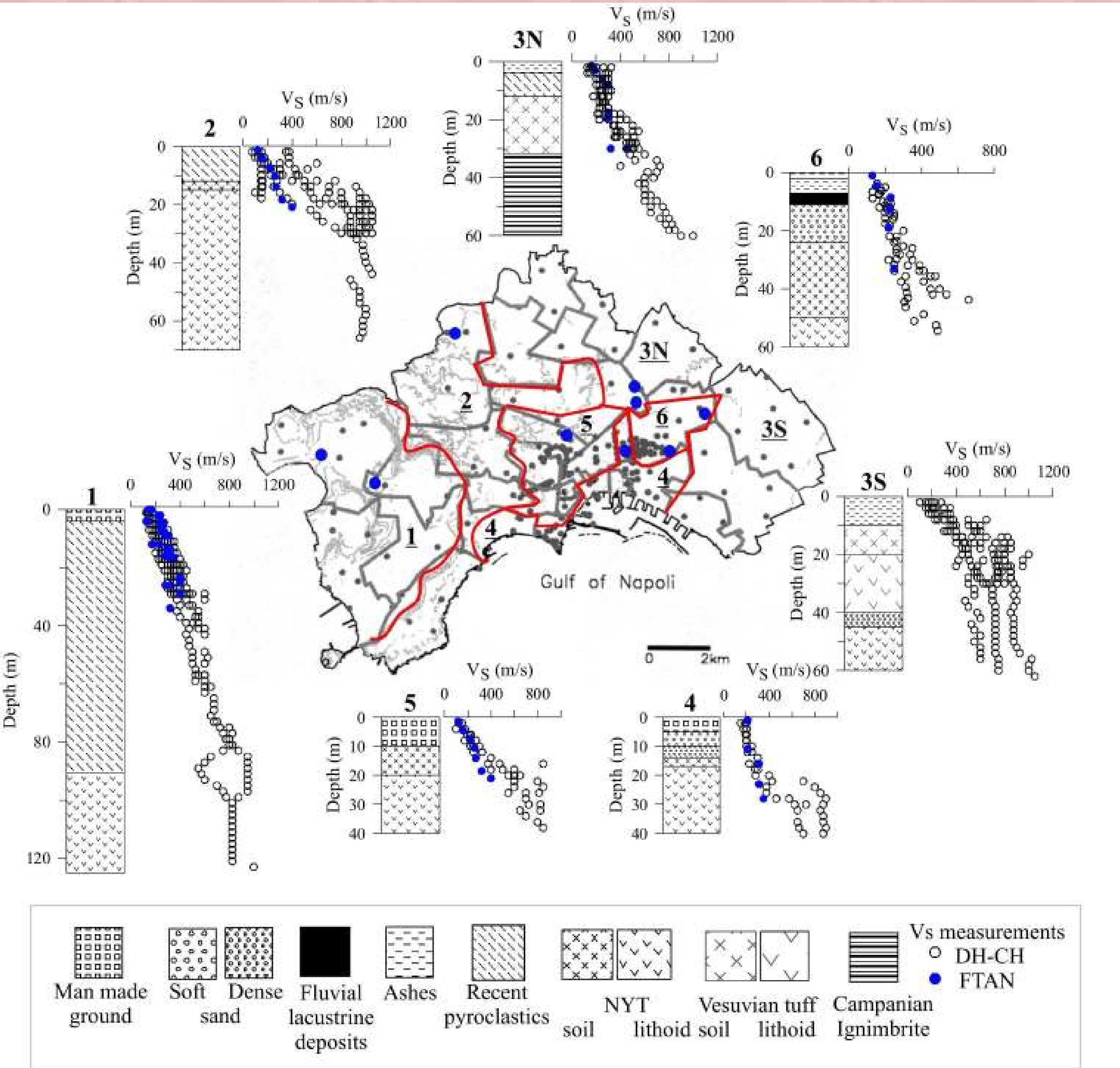


Phase velocities computed with **FTAN**, between signals at 50 and 80m offsets at Napoli (site 1), and **SASW** (Nazarian & Stokoe, 1985) methods. Phase velocities computed for **Hedgehog** solutions are also shown (dashed line) (Nunziata et al., 1999)

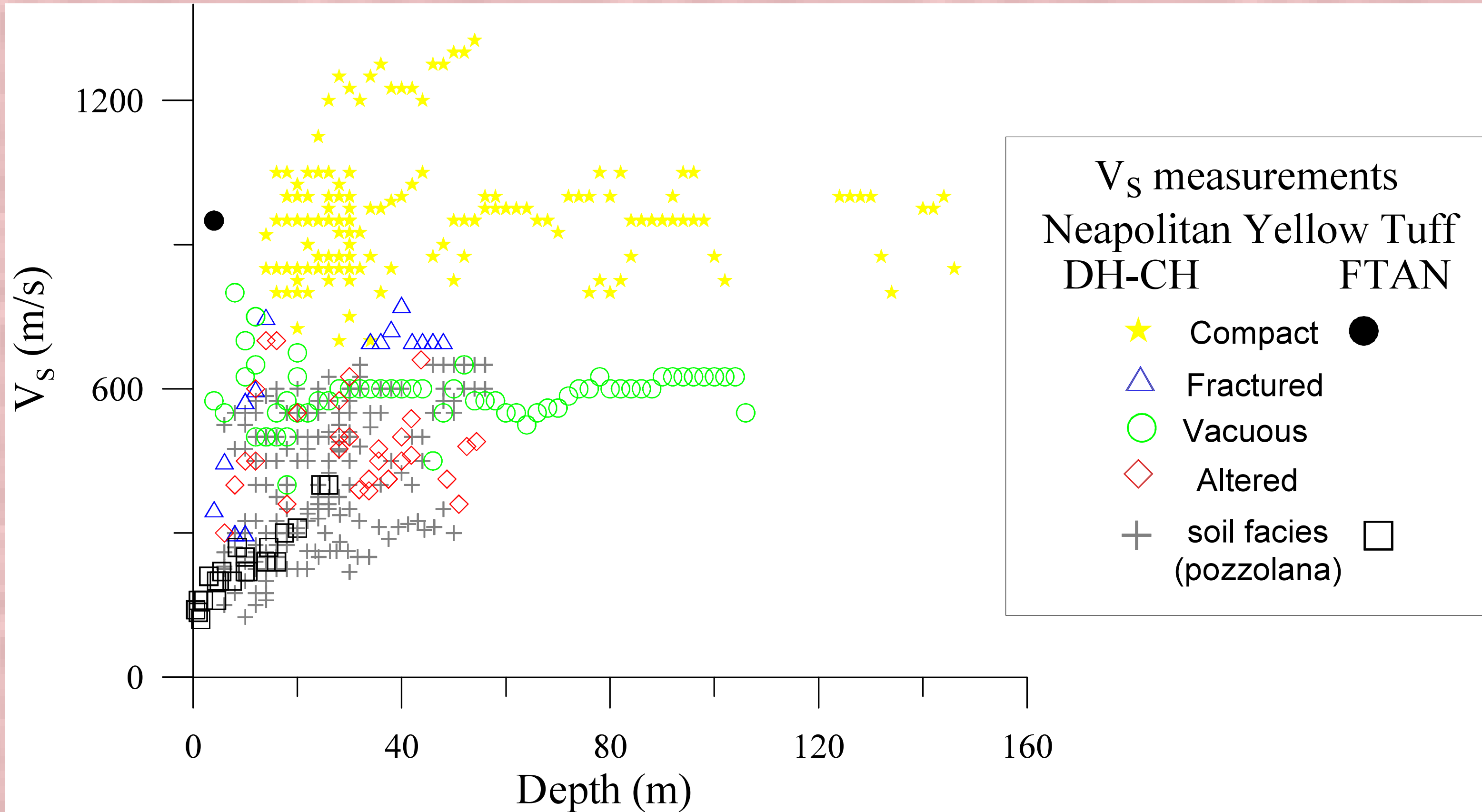
FTAN and hole measurements



Urban area of Napoli



Wide variability of V_S measurements of neapolitan soils



LIQUEFACTION EVALUATION PROCEDURE

- **cyclic stress ratio (CSR)**

$$CSR = \frac{\tau_{cyc}}{\sigma_V^{'}} = 0.65\frac{\tau_{max}}{\sigma_V^{'}}$$

simplified procedure

$$CSR = \frac{\tau_{cyc}}{\sigma_V^{'}} = 0.65\frac{a_{max}}{g}\frac{\sigma_V}{\sigma_V^{'}}r_d$$

- **cyclic resistance ratio (CRR).** Laboratory measurements on undisturbed specimens

or

Liquefaction case histories to characterize resistance in terms of measured in situ parameters

$$CRR = exp\left\{\frac{q_{c1N}}{540} + \left(\frac{q_{c1N}}{67}\right)^2 - \left(\frac{q_{c1N}}{80}\right)^3 + \left(\frac{q_{c1N}}{114}\right)^4 - 3\right\}$$

Liquefaction can occur when CRR<CSR

V_S based procedure

(Andrus and Stokoe, 2000; Stokoe et al., 2004)

The *CRR*-V_{S1} curves separating liquefaction and nonliquefaction:

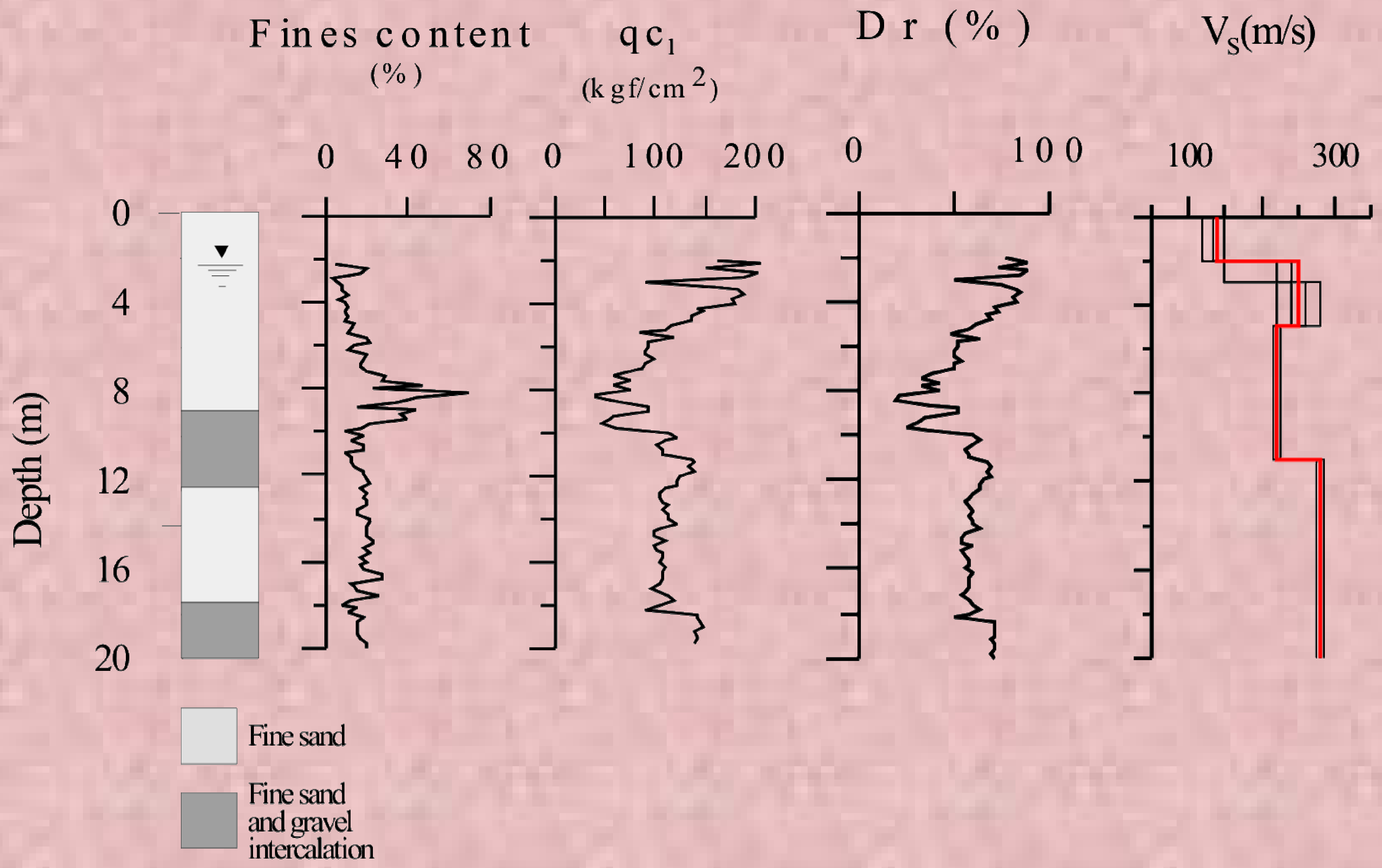
$$CRR = MSF\left\{0.022\left(\frac{K_{a1}V_{S1}}{100}\right)^2 + 2.8\left(\frac{1}{V_{S1}^* - (K_{a1}V_{S1})} - \frac{1}{V_{S1}^*}\right)\right\}K_{a2}$$

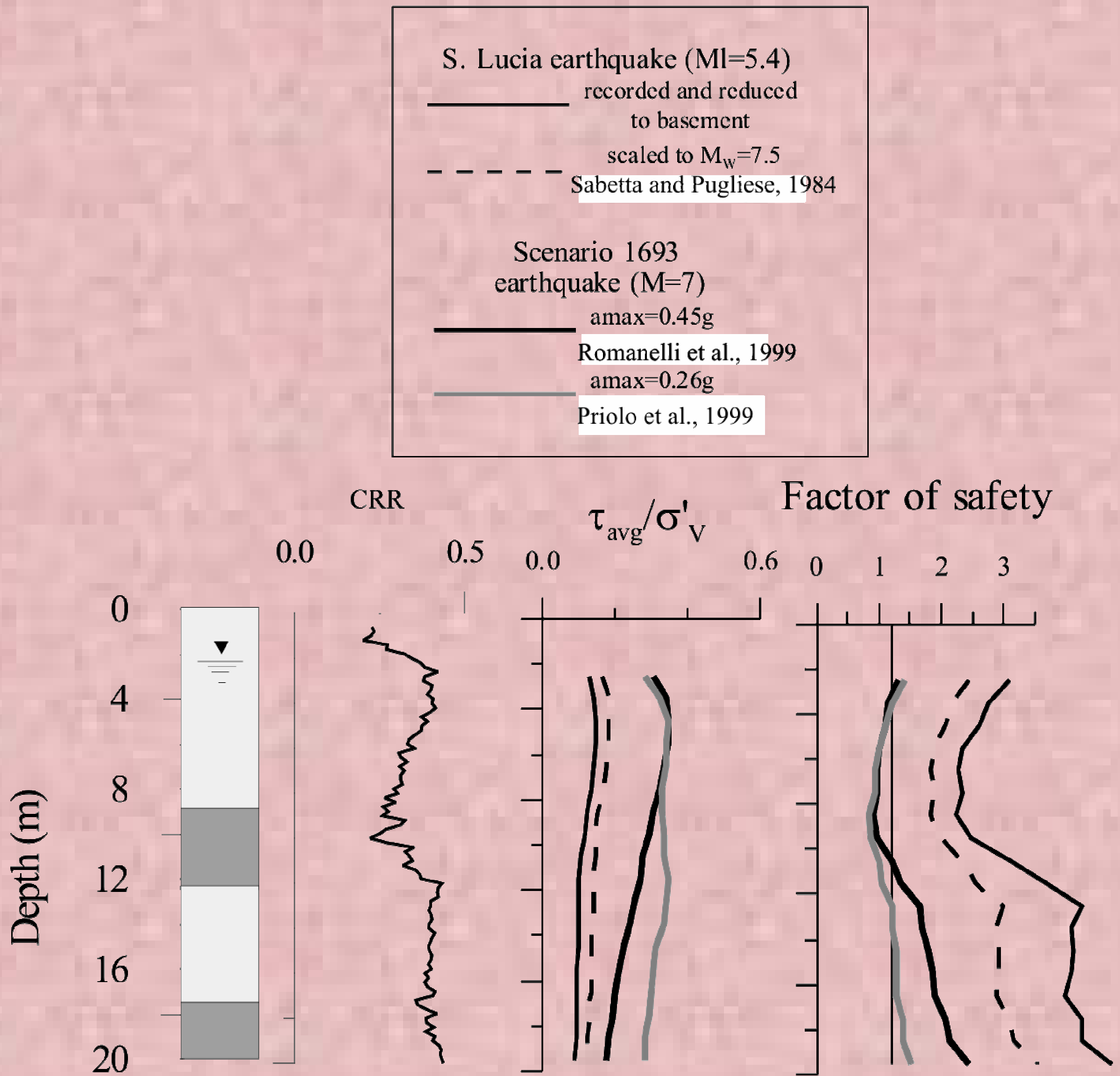
V_{S1}^* is the limiting upper value of V_{S1} for liquefaction occurrence, *and* is defined depending on the average fines content (FC) of soils as:

The factors K_{a1} and K_{a2} are 1.0 for uncemented soils of Holocene age, and, for older soils, they can be estimated with methods based on local SPT-V_{S1} equations and measurements.

Liquefaction susceptibility at Catania

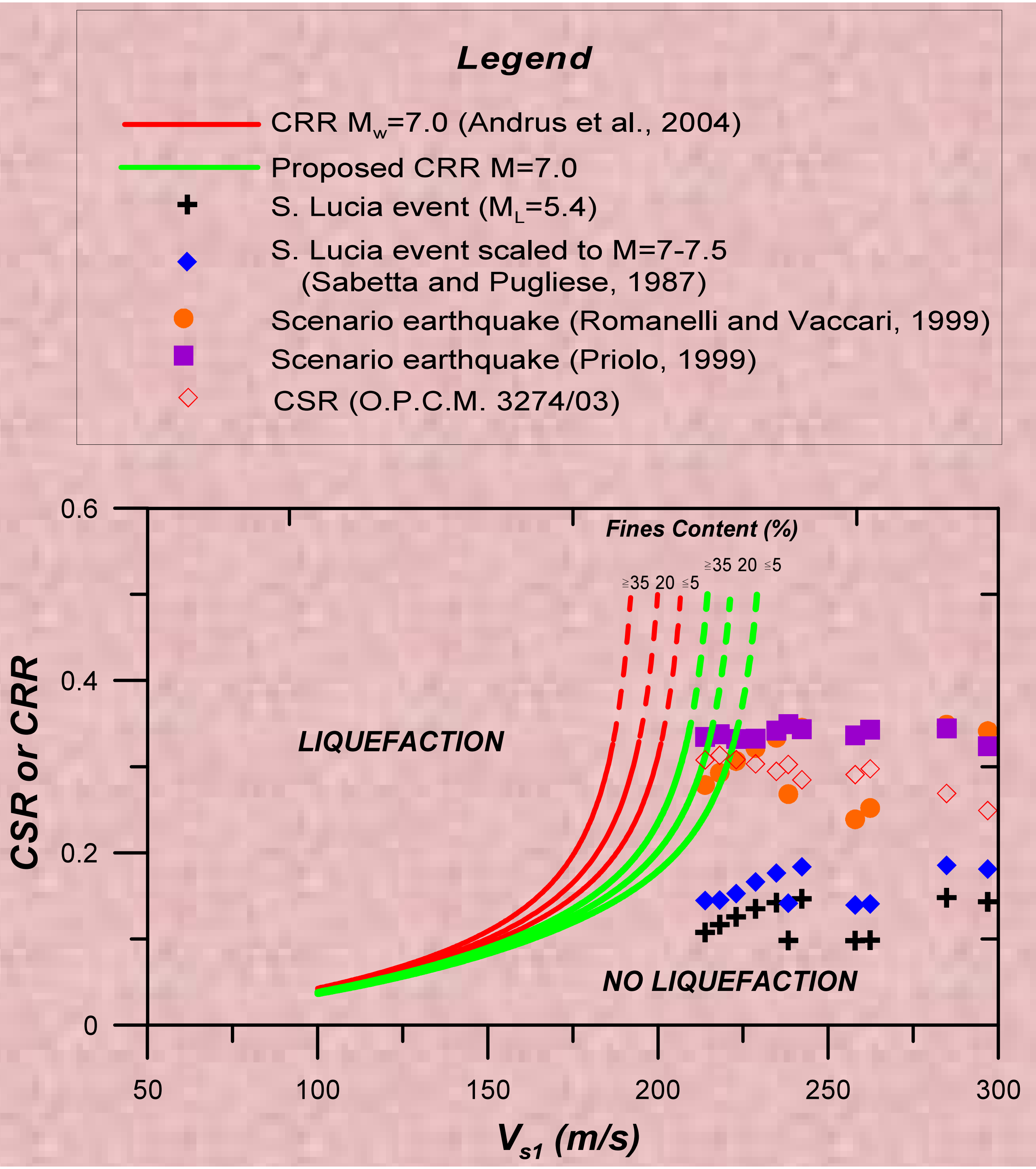
Nunziata C., De Nisco G. and Panza G.F., 2008. Evaluation of liquefaction potential for building code. Springer, Vol. 1020, Santini A. and Moraci N. Editors.



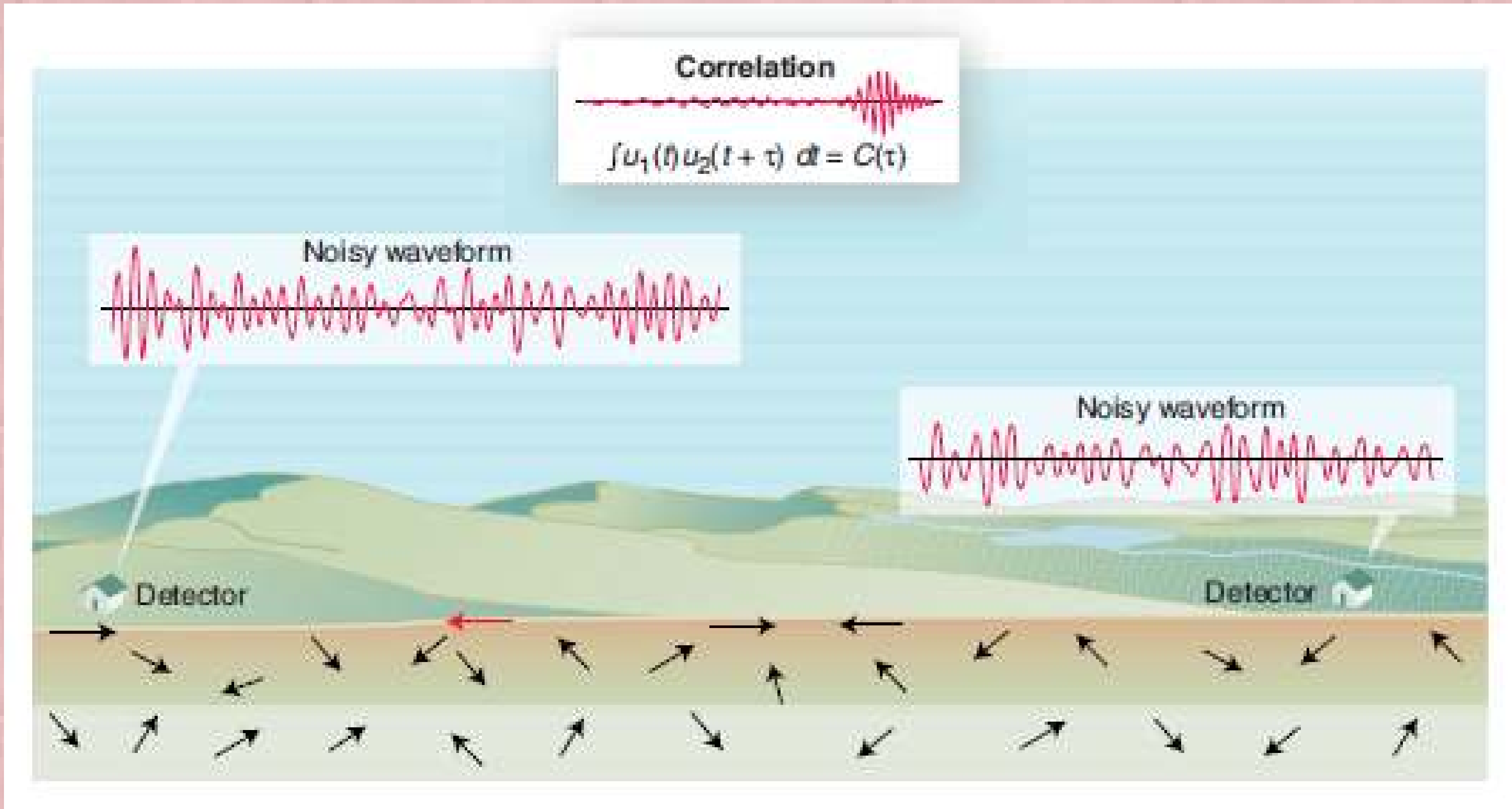


S. Lucia earthquake (Ml=5.4)
recorded and reduced to basement
scaled to M_w=7.5
Sabetta and Pugliese, 1984
Scenario 1693 earthquake (M=7)
amax=0.45g
Romanelli et al., 1999
amax=0.26g
Priolo et al., 1999
CRR
0.0
0.5
τ_{avg}/σ'_V
0.0
0.6
Factor of safety
0
1
2
3
Depth (m)
0
4
8
12
16
20

A method of screening if the liquefaction hazard is high or not

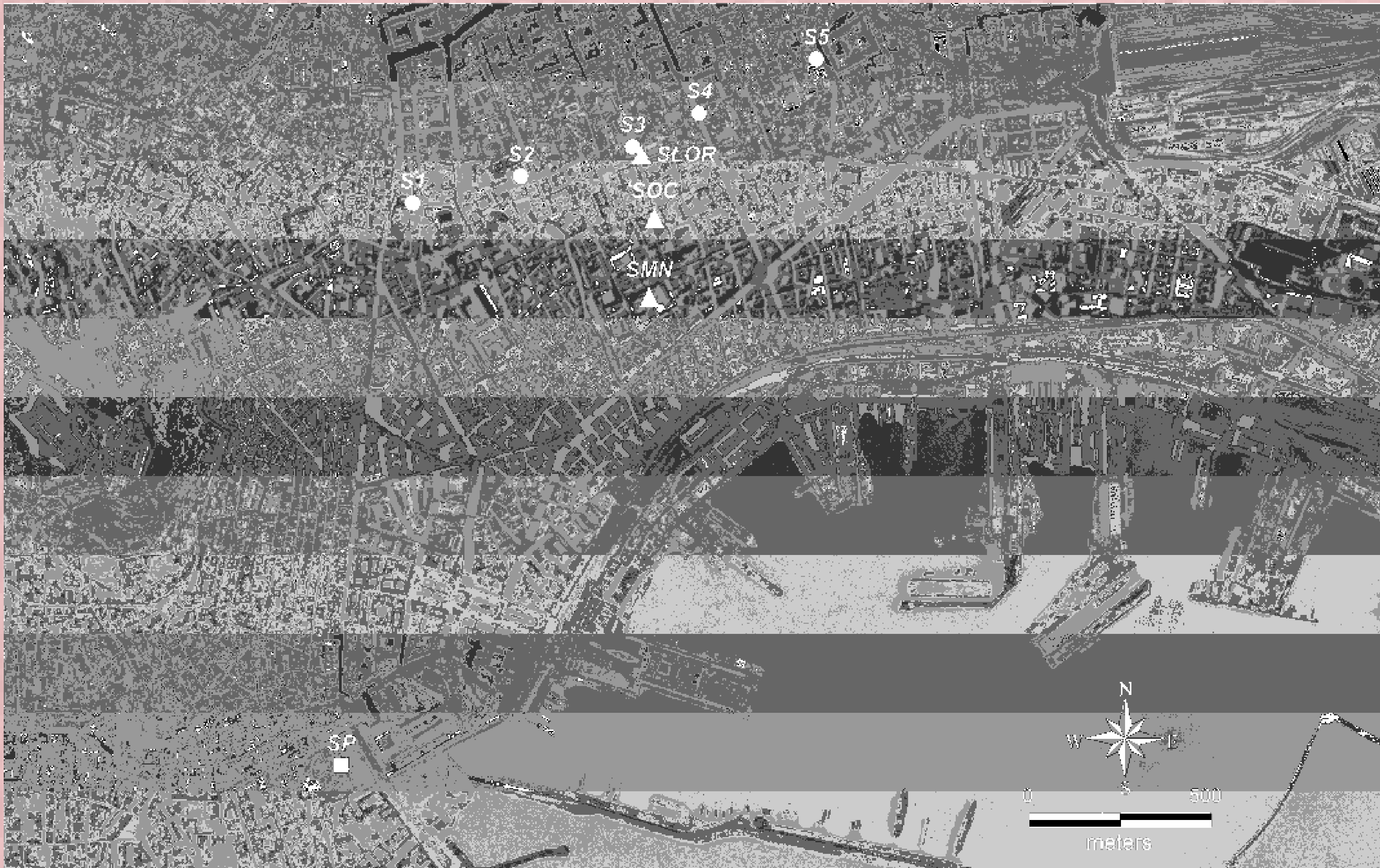


New approach: noise cross correlation

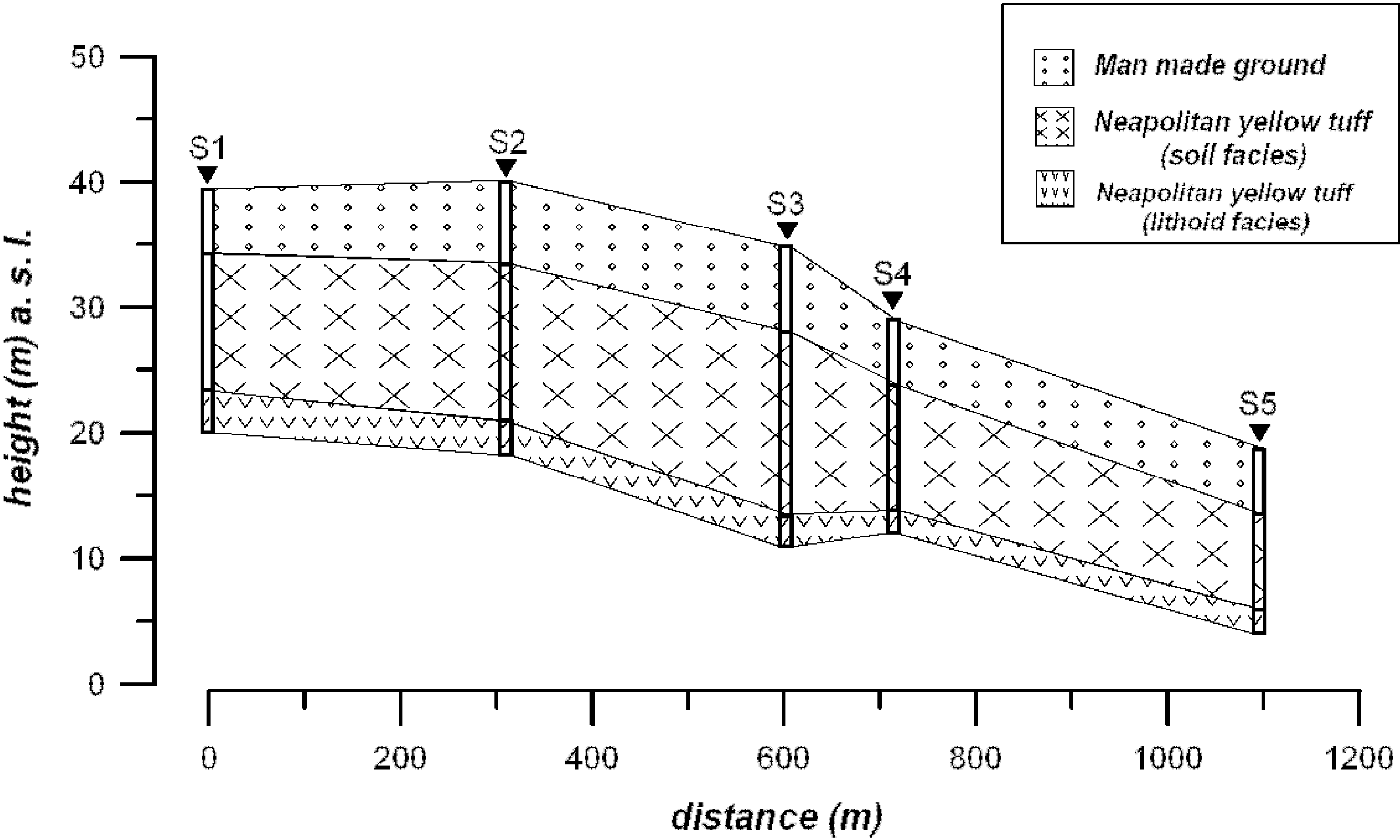


Engineering scale

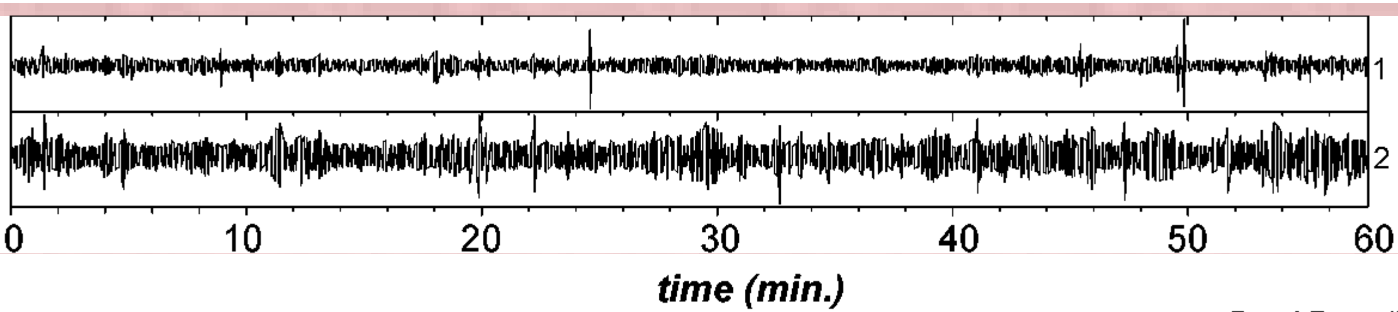
Nunziata C., De Nisco G., Panza G.F., 2009. S-waves profiles from noise cross correlation at small scale. Eng. Geol., 105, 161-170

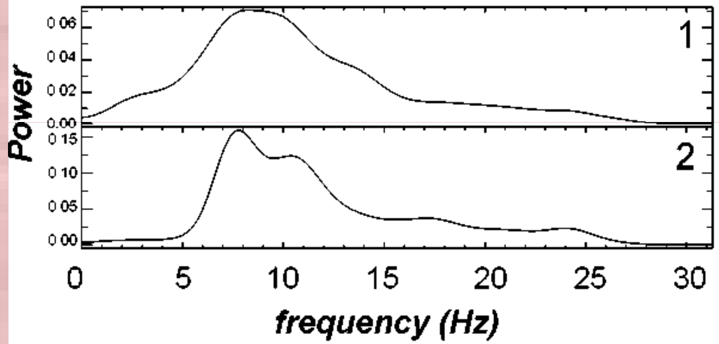


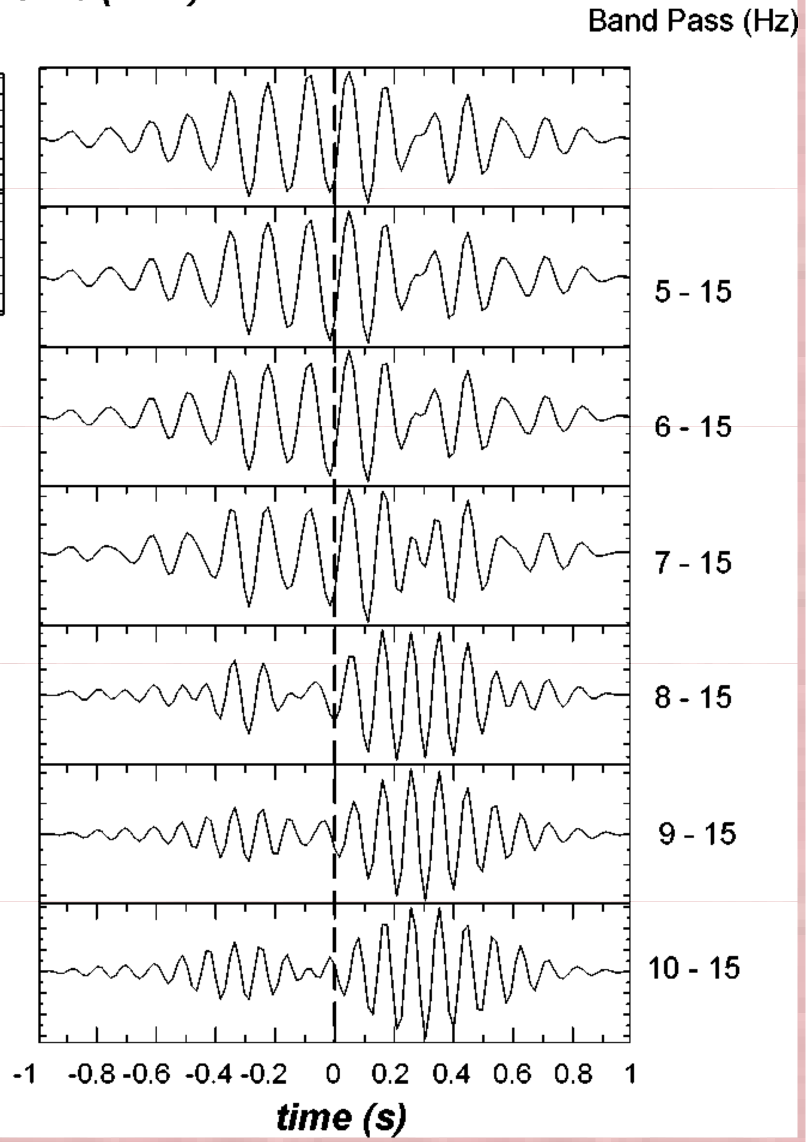
Seismic stations (full triangles) and drillings at the historical centre of Napoli


Man made ground
Neapolitan yellow tuff
(soil facies)
Neapolitan yellow tuff
(lithoid facies)
S1
S2
S3
S4
S5
50
40
30
20
10
0
height (m) a. s. l.
0
200
400
600
800
1000
1200
distance (m)

Example of noise analysis:

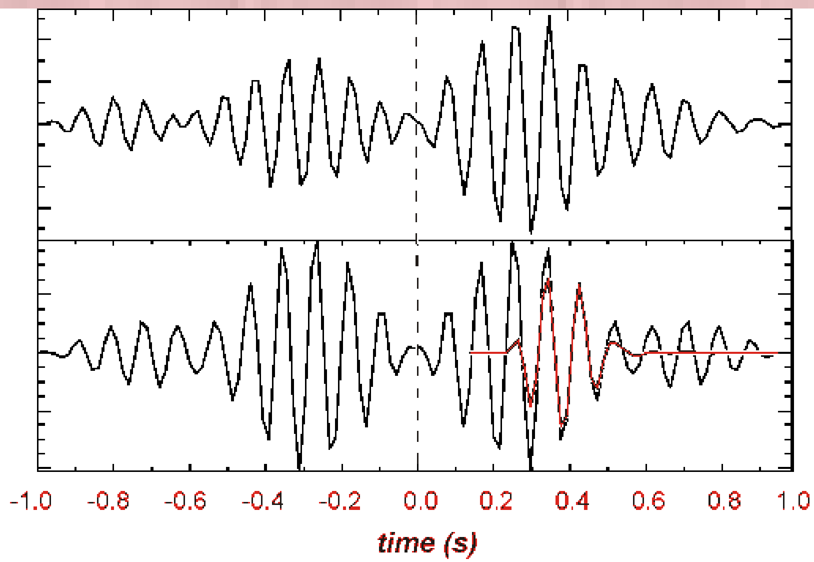




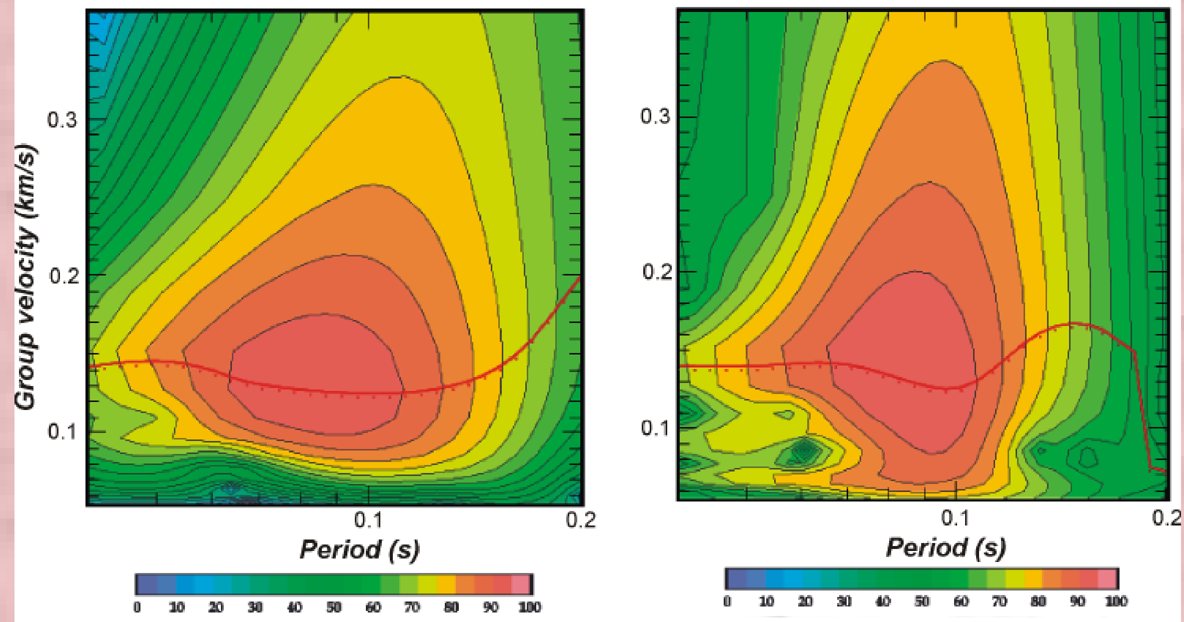


noise recordings with 1 Hz vertical geophones 50 m apart at S. Marcellino courtyard;

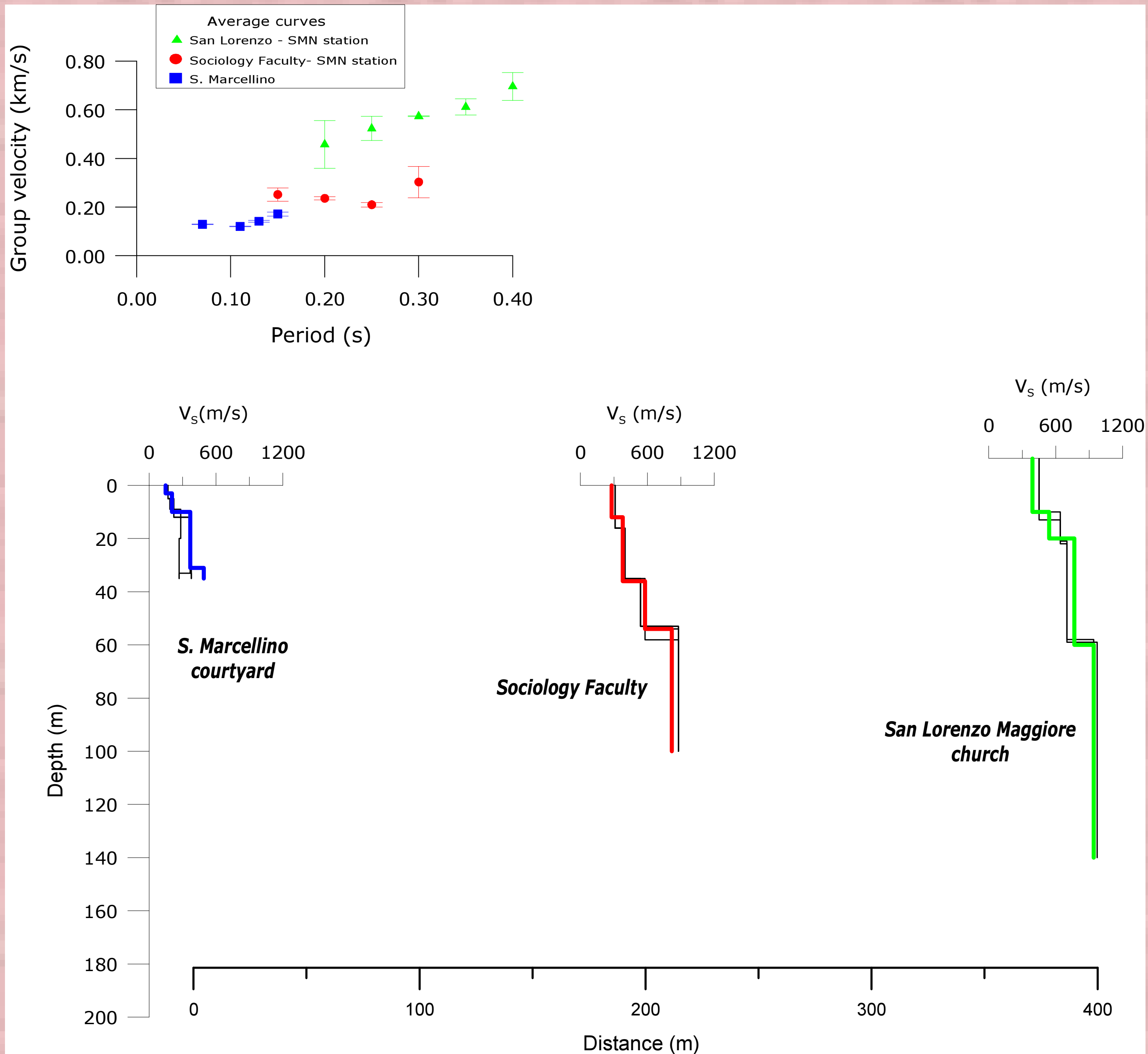
cross correlation of signals and band-pass filtered from 5-15 Hz to 10-15 Hz.



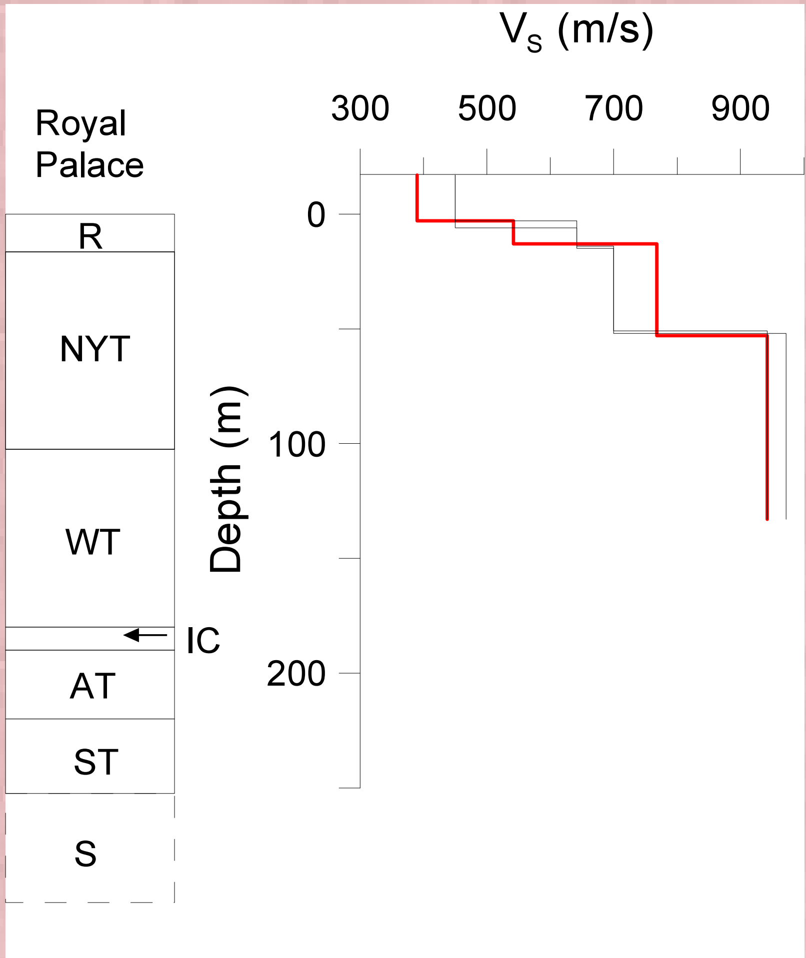
Cross correlation of 10-15 Hz band-pass filtered signals and its symmetric computed as average of cross correlation and its reverse. The fundamental mode Green function extracted with FTAN method (red) is overlapped.



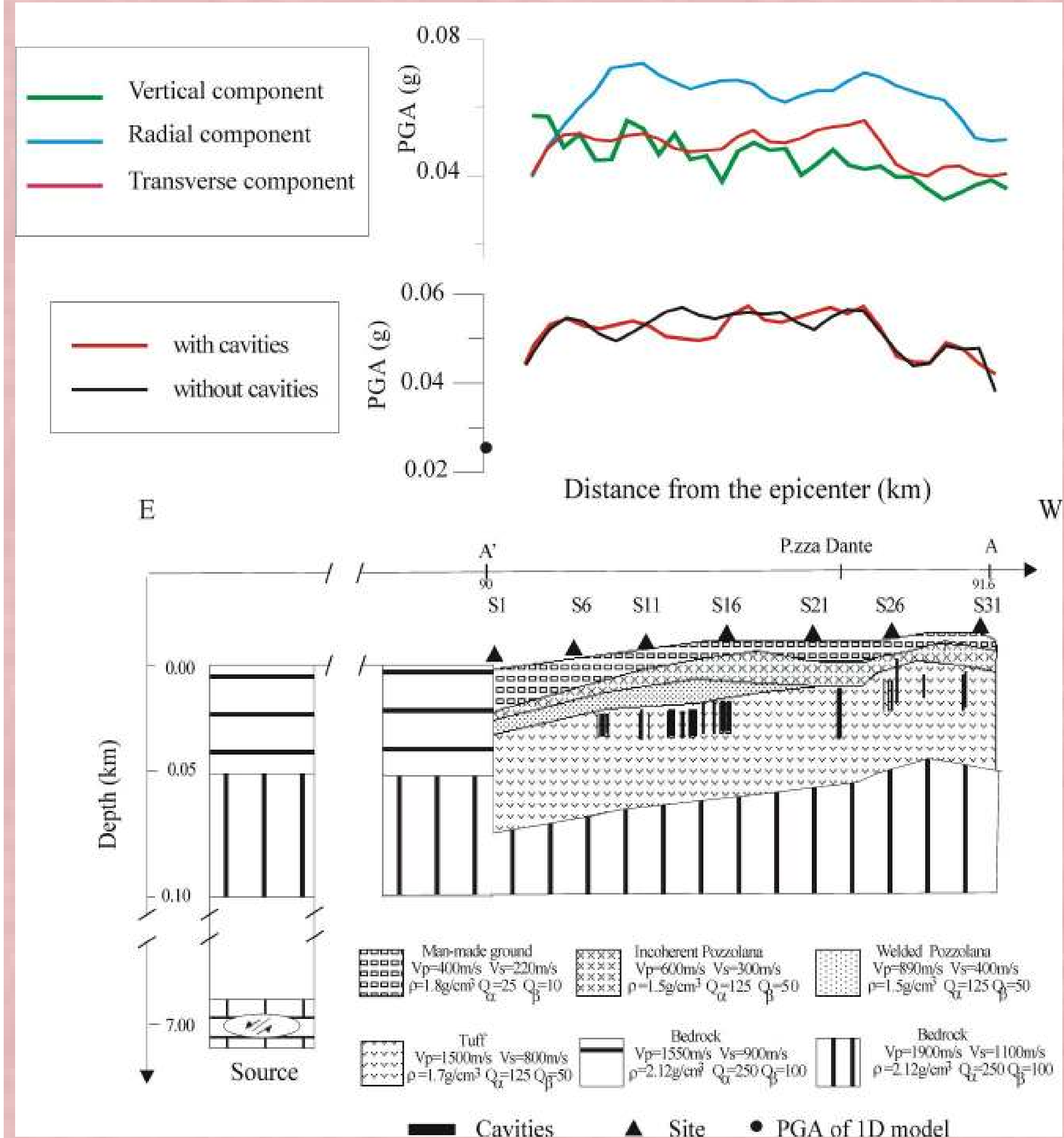
Raw and cleaned FTAN maps of symmetric cross correlations



Average curves
San Lorenzo - SMN station
Sociology Faculty- SMN station
S. Marcellino
Group velocity (km/s)
Period (s)
Vs(m/s)
Depth (m)
S. Marcellino courtyard
Sociology Faculty
San Lorenzo Maggiore church
Distance (m)



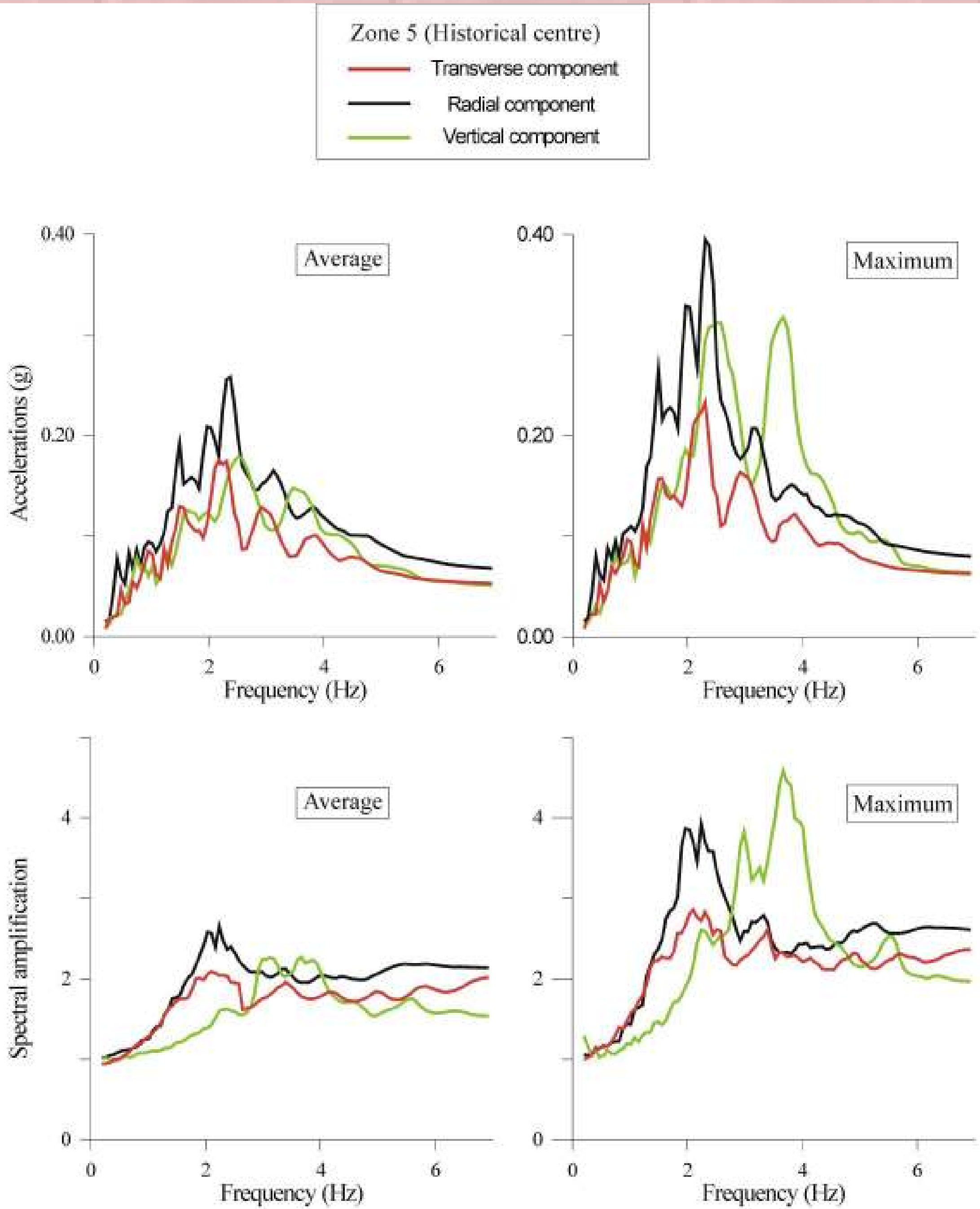
The V_S solutions for S. Lorenzo church- SMN path compared with the stratigraphy of the deep drilling at Royal palace



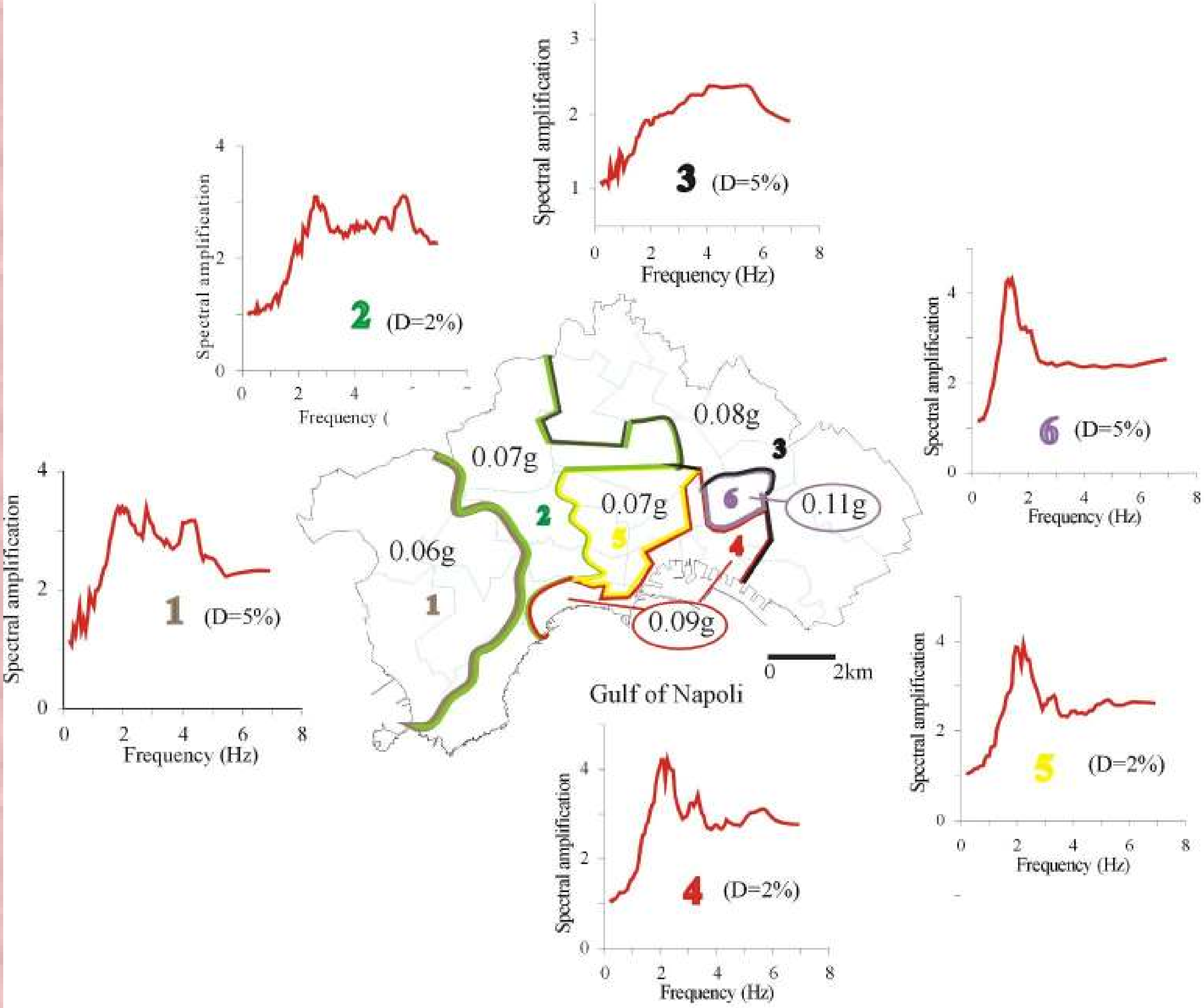
1980 earthquake
(*Nunziata*, 2004)

# of ground motion

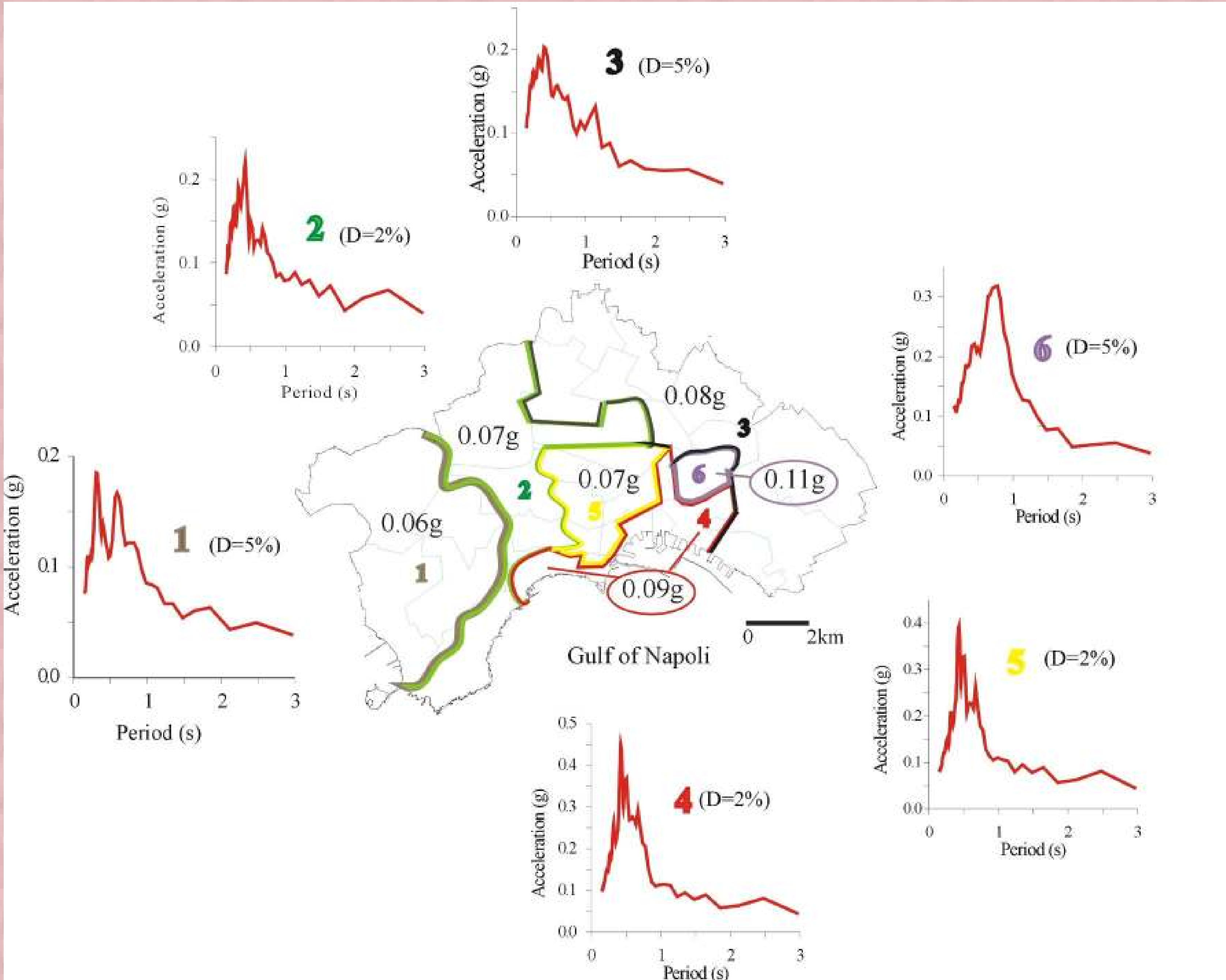
Average and maximum spectral amplifications and response spectra (2% Damping) computed for the SH and P-SV wave components at zone 5, along the cross section A'A (*Nunziata*, 2004)



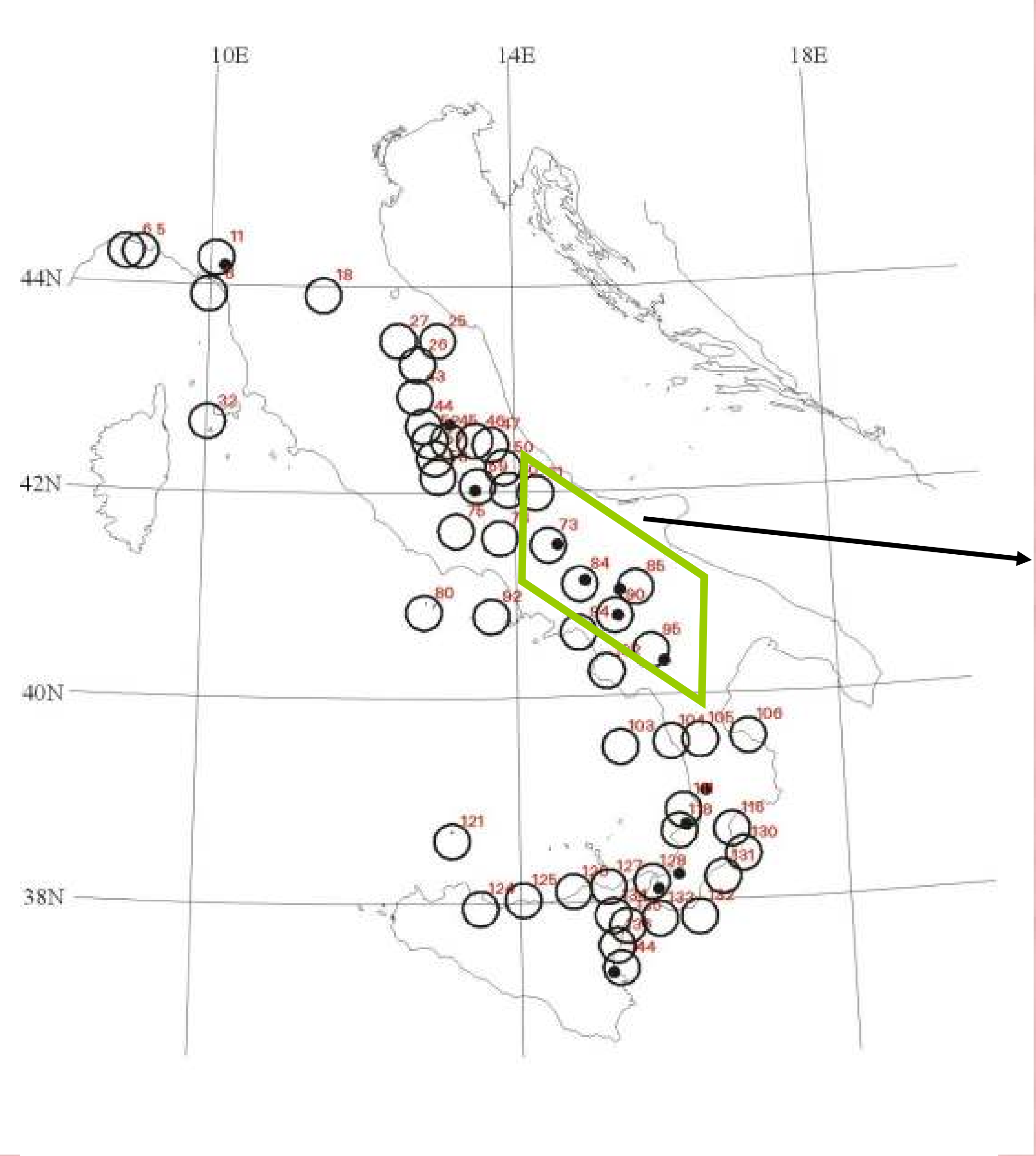
Maximum spectral amplification of radial component



Maximum response spectra of radial component



Seismogenic nodes for earthquakes M≥6.5 in Italy peninsula and Sicily

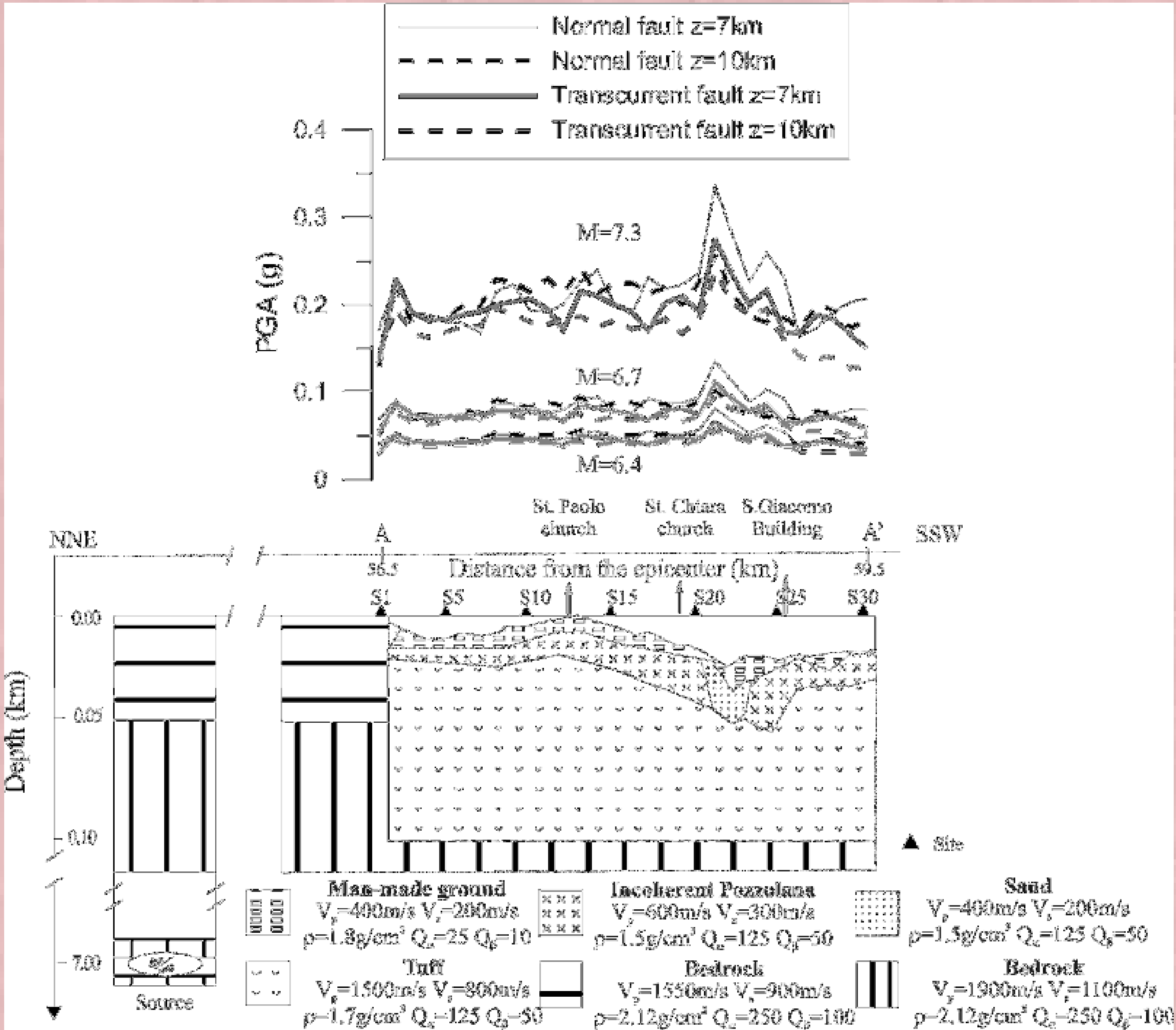


Historical Strong Earthquakes In Napoli

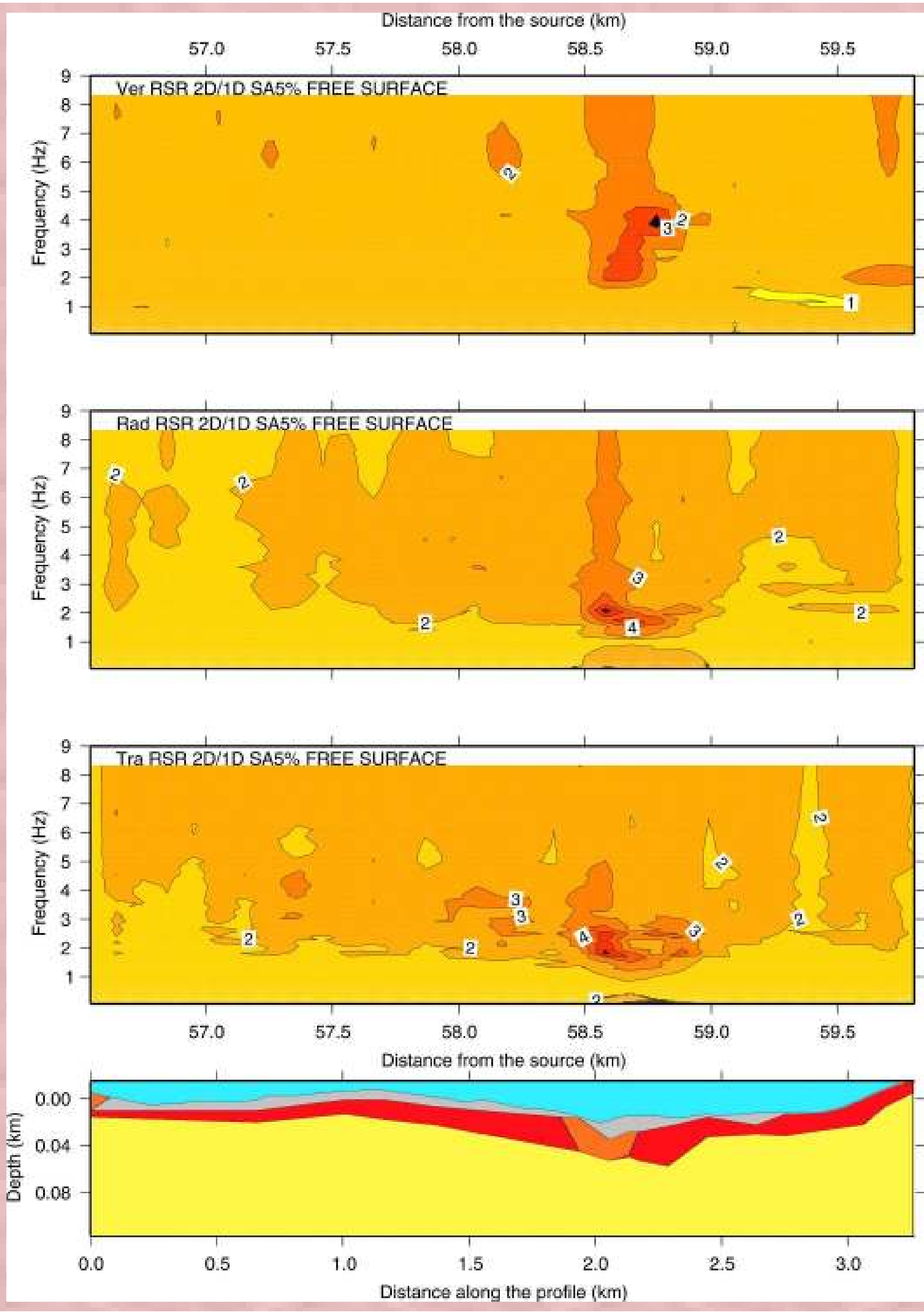
earthquake	node
1456	84
1688	73
1694	90
1805	73
1857	95
1930	85
1962	84
1980	90

	Earthquake December 12, 1456				Earthquake June 5, 1688			
Catalogue	CFTI	NT4.1	CPTI04	CCI1996	CFTI	NT4.1	CPTI04	CCI1996
Latitude	41.30°	41.15°	41.30°	41.27°	41.28°	41.32°	41.28°	41.33°
Longitude	14.72°	14.87°	14.71°	14.77°	14.57°	14.57°	15.57°	14.67°
Magnitude	7.1	6.7	6.9	6.6	6.6	7.3	6.7	6.6
Ix	11	11	11		11	11	11	
Is Napoli	8	8			8	7-8		

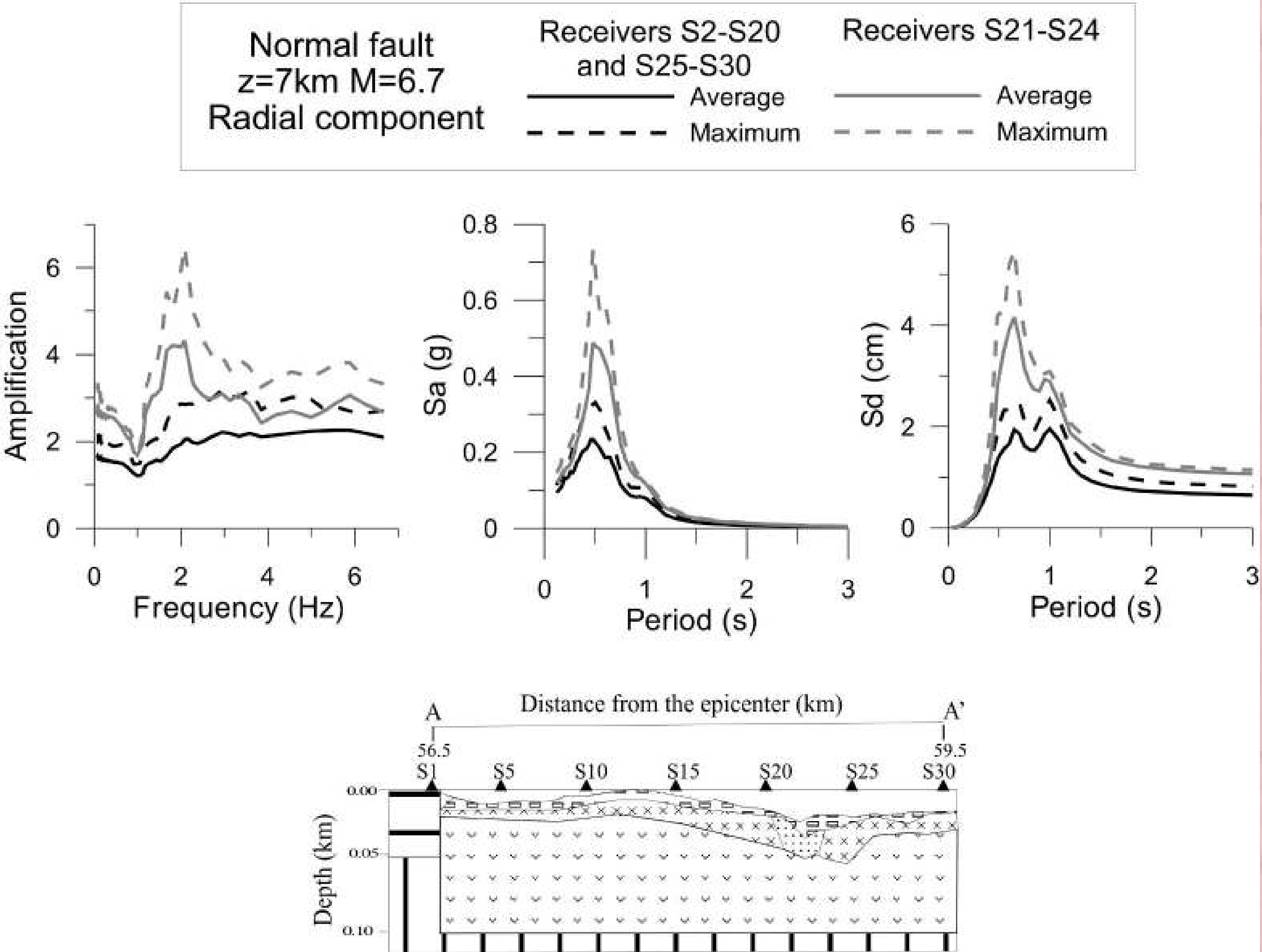
Red: high damage; yellow: medium damage; green: low damage



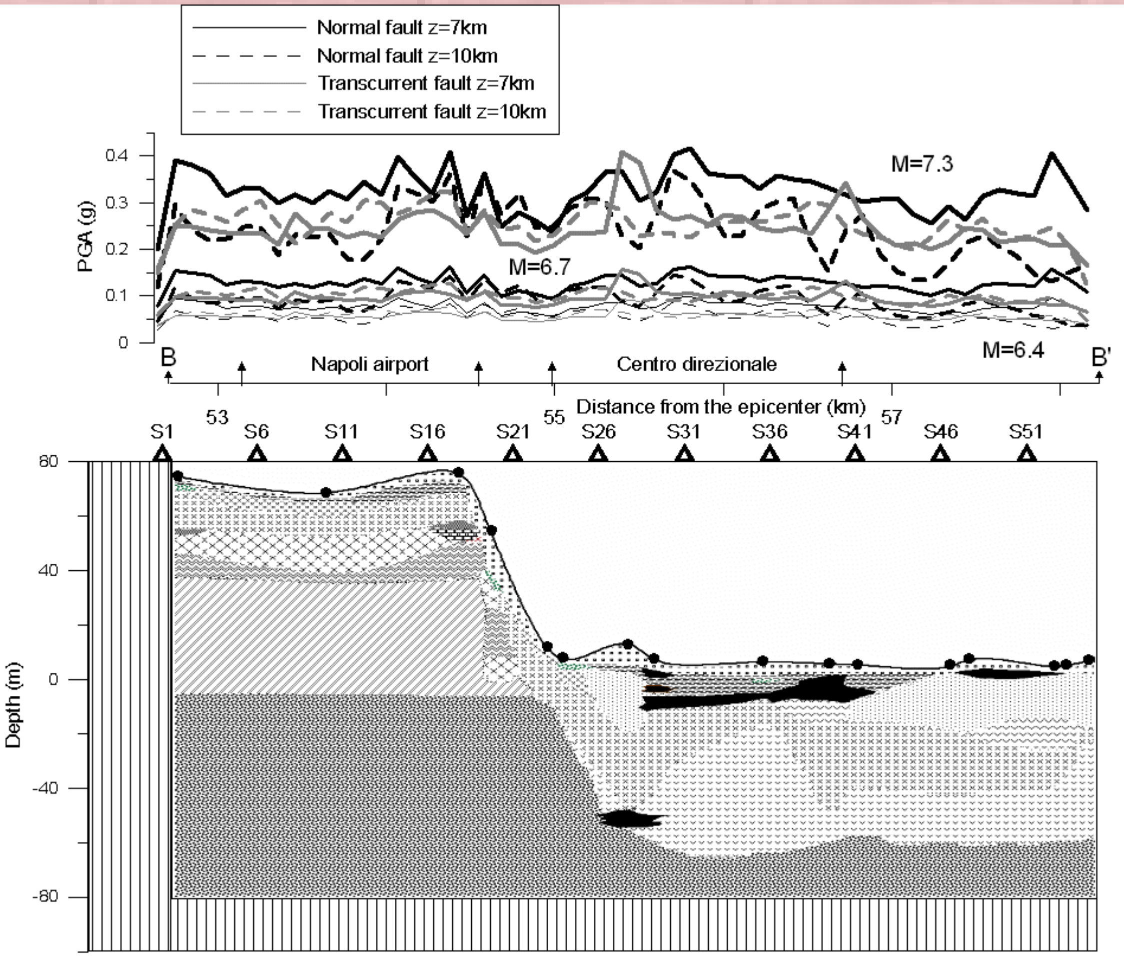
Normal fault z=7km
Normal fault z=10km
Transcurrent fault z=7km
Transcurrent fault z=10km
PGA (g)
0.4
0.3
0.2
0.1
0
M=7.3
M=6.7
M=6.4
St. Paolo church
St. Chiara church
S.Giacomo Building
NNE
A
A'
SSW
Distance from the epicenter (km)
S1
S5
S10
S15
S20
S25
S30
Depth (km)
0.00
0.05
0.10
7.00
Source
Site
Man-made ground
Incoherent Pozzolana
Sand
Tuff
Bedrock
Bedrock

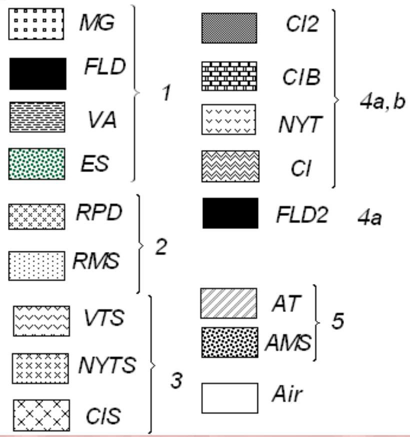


Distance from the source (km)
57.0
57.5
58.0
58.5
59.0
59.5
Frequency (Hz)
Ver RSR 2D/1D SA5% FREE SURFACE
Rad RSR 2D/1D SA5% FREE SURFACE
Tra RSR 2D/1D SA5% FREE SURFACE
Depth (km)
0.00
0.04
0.08
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance along the profile (km)

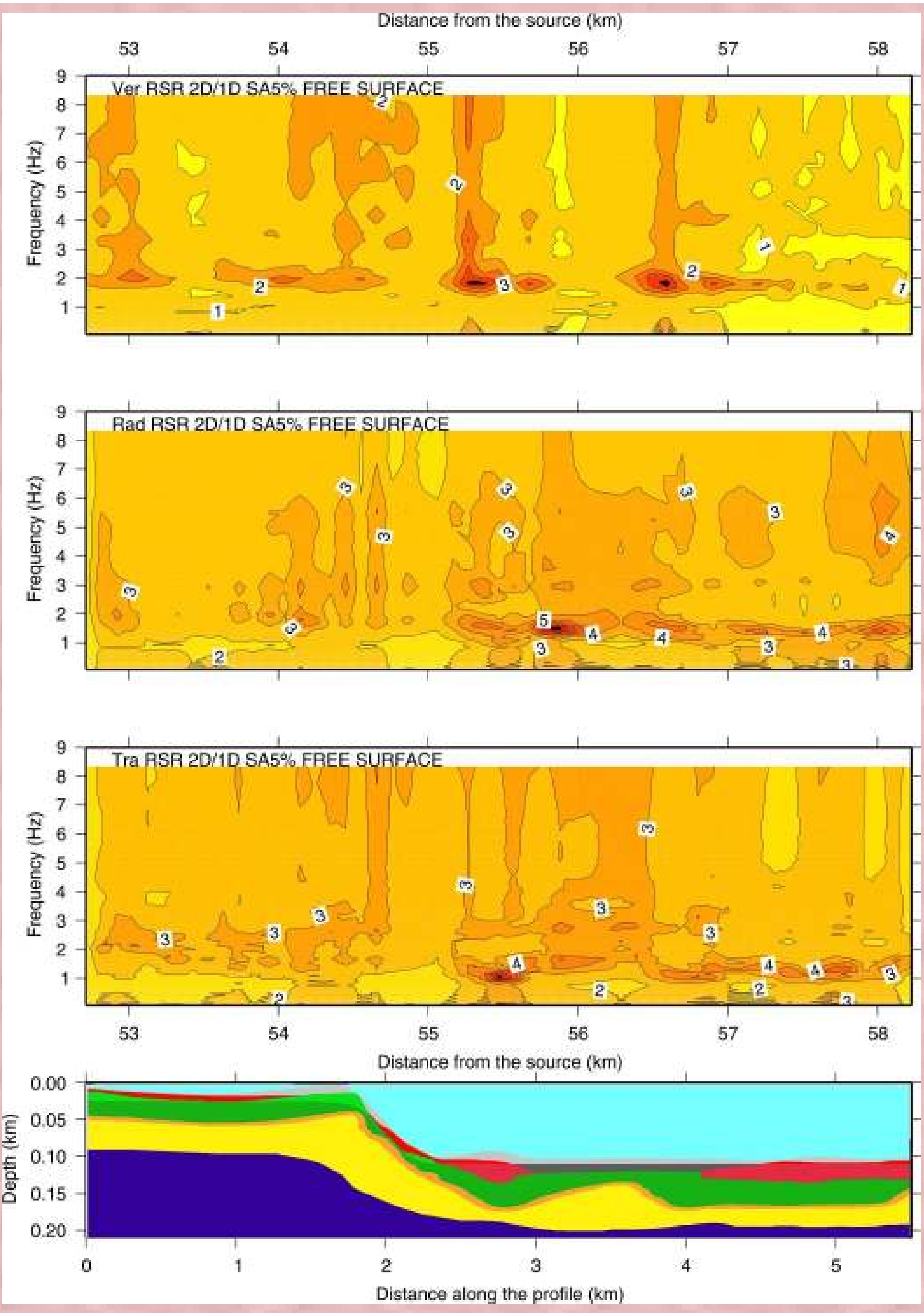


Normal fault
z=7km M=6.7
Radial component
Receivers S2-S20 and S25-S30
Average
Maximum
Receivers S21-S24
Average
Maximum
Amplification
Frequency (Hz)
Sa (g)
Period (s)
Sd (cm)
Period (s)
Distance from the epicenter (km)
A
A'
56.5
59.5
S1
S5
S10
S15
S20
S25
S30
Depth (km)

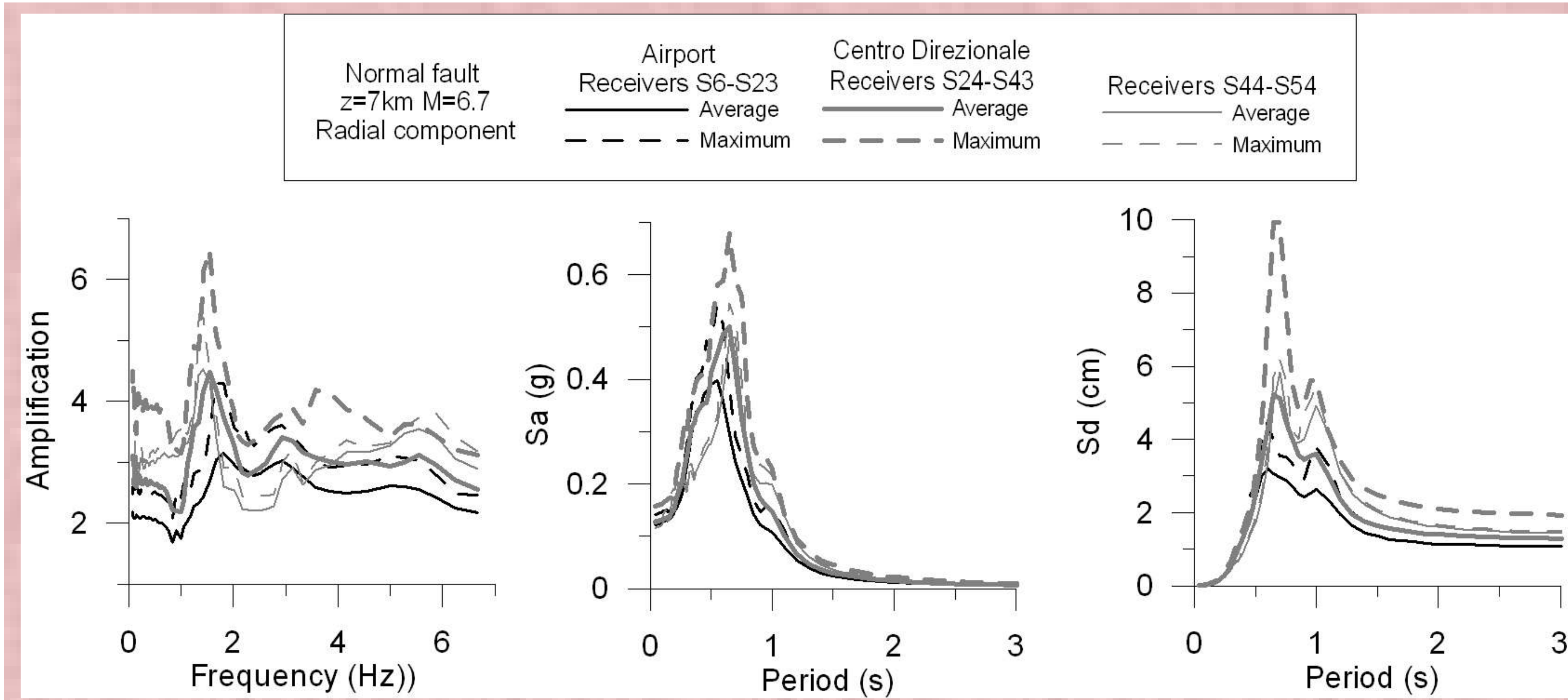


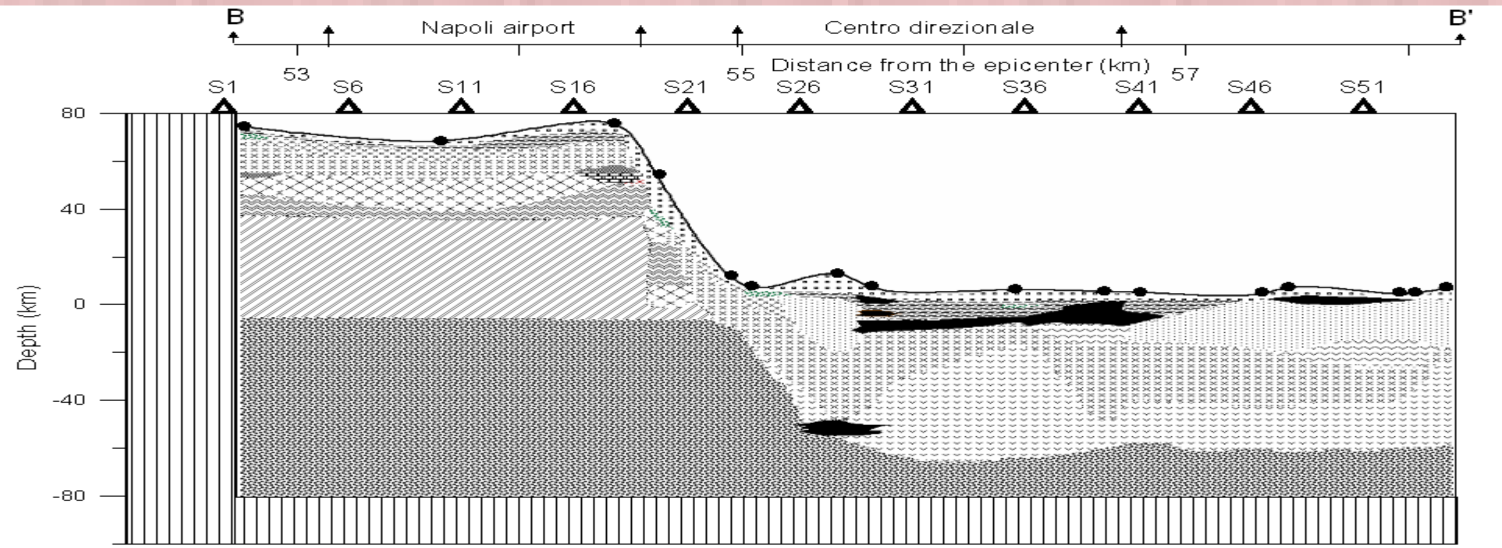


Layer	Water table	ρ (g/cm^3)	V_P (m/s)	Q_P	V_S (m/s)	Q_S
1	Above	1.5	400	40	200	15
	Below		1500			
2	Above	1.5	450	50	220	20
	Below		1500			
3	Above	1.5	550	125	260	50
	Below		1500		270	
4a	Below	1.7	1500	125	500	50
4b	Below	1.7	1500	125	600	50
5	Below	2.1	1600	250	900	100



Distance from the source (km)
Ver RSR 2D/1D SA5% FREE SURFACE
Rad RSR 2D/1D SA5% FREE SURFACE
Tra RSR 2D/1D SA5% FREE SURFACE
Frequency (Hz)
Distance from the source (km)
Depth (km)
Distance along the profile (km)


Normal fault
z=7km M=6.7
Radial component
Airport
Receivers S6-S23
Average
Maximum
Centro Direzionale
Receivers S24-S43
Average
Maximum
Receivers S44-S54
Average
Maximum
Amplification
Frequency (Hz))
Sa (g)
Period (s)
Sd (cm)
Period (s)

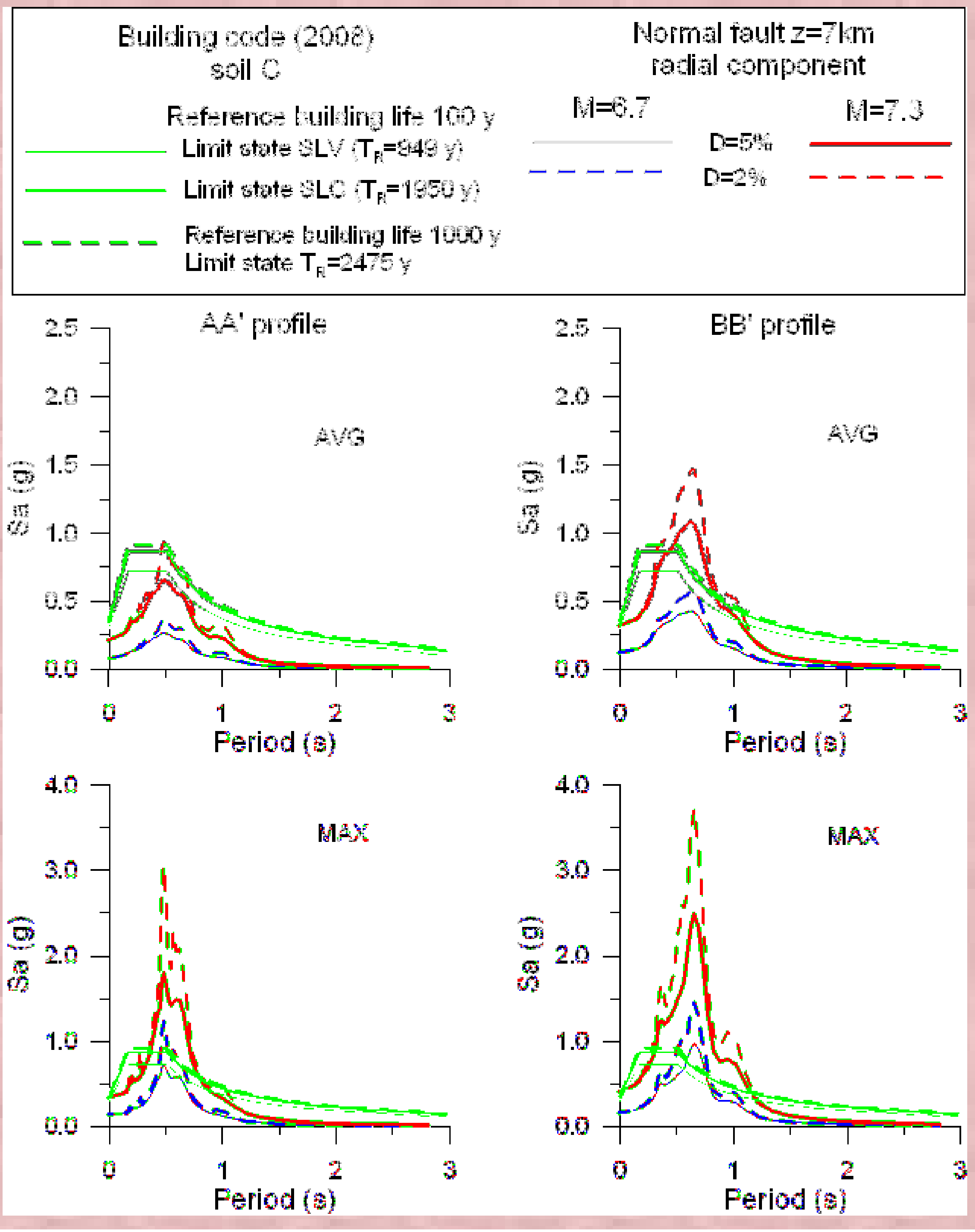

B
B'
Napoli airport
Centro direzionale
Distance from the epicenter (km)
53
55
57
S1
S6
S11
S16
S21
S26
S31
S36
S41
S46
S51
Depth (km)
80
40
0
-40
-80

Correlations computed P.G.A. – observed intensities

(Panza et al., 1999)

Observed Intensity at Napoli = VII and VIII

Magnitude	Range	source depth 7km		Catalogue		source depth 10km		Catalogue	
		N7	T7	ING	ISG	N10	T10	ING	ISG
M=6.4	Max	0.08	0.07	VIII	VIII	0.06	0.06	VIII	VIII
	Min	0.03	0.03	VII	VII	0.03	0.03	VII	VII
M=6.7	Max	0.13	0.11	IX	IX	0.10	0.10	VIII	VIII
	Min	0.05	0.05	VIII	VII	0.05	0.05	VIII	VII
M=7.3	Max	0.33	0.27	XI	X	0.25	0.23	X	X
	Min	0.14	0.13	IX	IX	0.13	0.12	IX	IX



Building code (2008)
soil C
Reference building life 100 y
Limit state SLV (T_R=949 y)
Limit state SLC (T_R=1950 y)
Reference building life 1000 y
Limit state T_R=2475 y
Normal fault z=7km
radial component
M=6.7
M=7.3
D=5%
D=2%
AA' profile
BB' profile
AVG
MAX
Sa (g)
Period (s)

CONCLUSIONS

The neo-deterministic approach is capable to provide, in a reasonable amount of time, large sets of realistic seismic signals and related quantities of earthquake engineering interest.

Key points for microzonation studies are a detailed geological study and a robust definition of Vs profiles with depth, obtainable from the non linear inversion of Rayleigh group velocities. The method is particularly expeditious and suitable in highly noisy and urbanized centers.

Napoli is a good example of application of the hybrid method and supports that a preventive definition of the seismic hazard can be obtained immediately, without having to wait for another strong event to occur.