Integrated Multiscale Hazard Scenarios

Intermediate-term medium-range earthquake predictions (CN, M8S)

Restrained area for expected sources + time

Pattern recognition of earthquake prone areas (nodes)

Multiscale structural models

Seismic sources characterization

Multiscale Ground motion scenarios

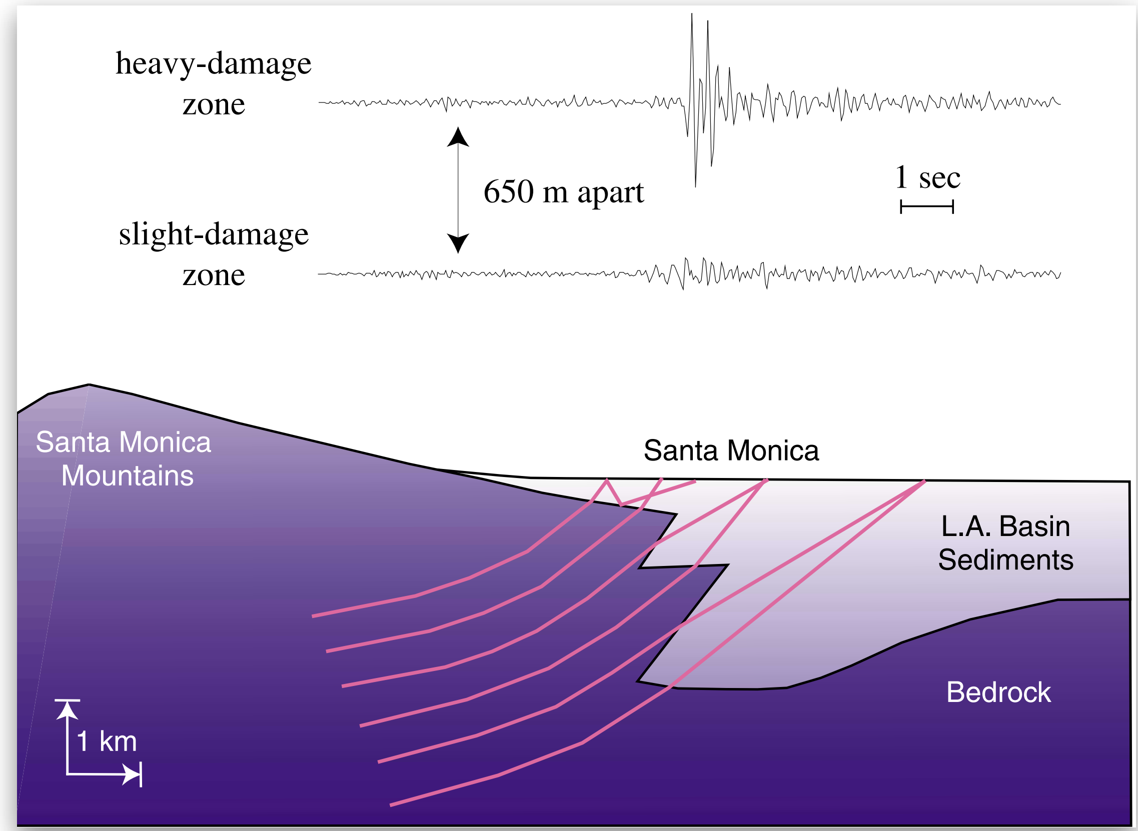
Space& time info for Seismic Risk

Seismic Input for engineering analysis

SURFACE TOPOGRAPHY EFFECTS

(convexity) sensitivity to:

a) type of wavefield
b) angle of incidence
c) shape and sharpness



GROUNDSHAKING SITE EFFECTS

SOFT SURFACE LAYERING

a) 1-D: trapping of waves for impedance contrast; vertical resonances
$fn=[(2n+1)\beta]/4H$; $A \approx (\rho_2 v_2)/(\rho_1 v_1)$

b) 2/3-D 3-D: complex energy focusing; diffraction effects;
basin edge waves

EMPIRICAL TECHNIQUES FOR SITE EFFECT ESTIMATION

WEAK (AND STRONG) MOTION

a) S/B spectral ratio (Borcherdt, 1970)
b) generalized inversion scheme (Andrews, 1986)
c) coda waves analysis (Margheriti et al., 1994)
d) parametrized source and path inversion (Boatwright et al., 1991)
e) H/V spectral ratio (receiver function) (Lermo et al., 1993)

$$R_{ij}(\omega) = E_i(\omega) \cdot P_{ij}(\omega) \cdot S_j(\omega)$$

MICROTREMORS

a) peak frequencies examination
b) S/B spectral ratio
c) H/V spectral ratio (Nagoshi, 1971; Nakamura, 1989)
d) array analysis (Malagnini et al., 1993)

Site effects and SHA

- In SHA the site effect should be defined as the average behavior, relative to other sites, given all potentially damaging earthquakes

- This produces an intrinsic variability with respect to different earthquake locations, that cannot exceed the difference between sites

- Site characterization:

  - which velocity?

  - use of basin depth effect?

Site effects and Italian code

Categorie di sottosuolo

Ai fini della definizione dell'azione sismica di progetto, si rende necessario valutare l'effetto della risposta sismica locale mediante specifiche analisi, come indicato nel § 7.11.3. In assenza di tali analisi, per la definizione dell'azione sismica si può fare riferimento a un approccio semplificato, che si basa sull'individuazione di categorie di sottosuolo di riferimento (Tab. 3.2.II e 3.2.III).

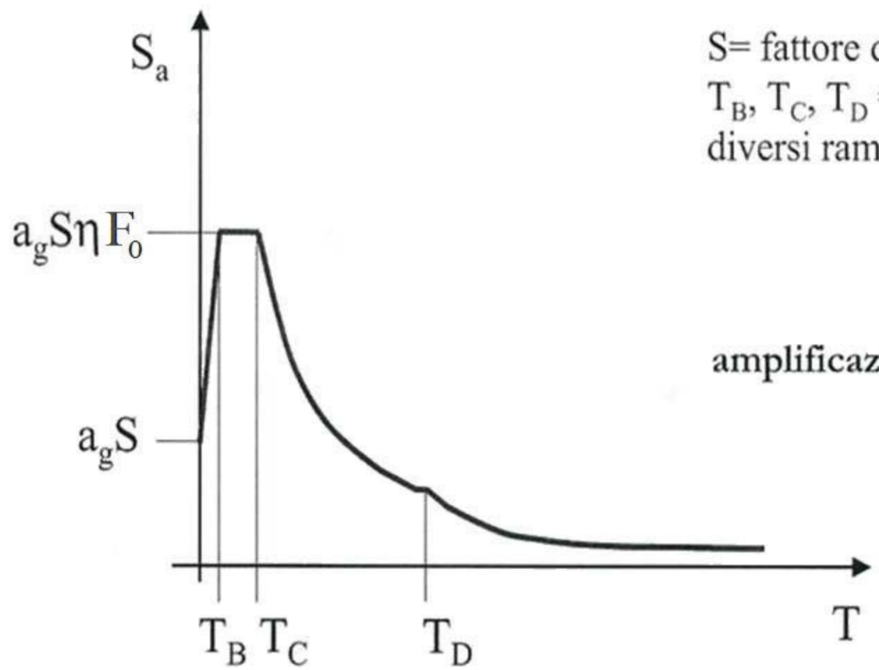
Tabella 3.2.II – *Categorie di sottosuolo*

Categoria	Descrizione
A	*Ammassi rocciosi affioranti o terreni molto rigidi* caratterizzati da valori di $V_{s,30}$ superiori a 800 m/s, eventualmente comprendenti in superficie uno strato di alterazione, con spessore massimo pari a 3 m.
B	*Rocce tenere e depositi di terreni a grana grossa molto addensati o terreni a grana fina molto consistenti* con spessori superiori a 30 m, caratterizzati da un graduale miglioramento delle proprietà meccaniche con la profondità e da valori di $V_{s,30}$ compresi tra 360 m/s e 800 m/s (ovvero $N_{SPT,30} > 50$ nei terreni a grana grossa e $c_{u,30} > 250$ kPa nei terreni a grana fina).
C	*Depositi di terreni a grana grossa mediamente addensati o terreni a grana fina mediamente consistenti* con spessori superiori a 30 m, caratterizzati da un graduale miglioramento delle proprietà meccaniche con la profondità e da valori di $V_{s,30}$ compresi tra 180 m/s e 360 m/s (ovvero $15 < N_{SPT,30} < 50$ nei terreni a grana grossa e $70 < c_{u,30} < 250$ kPa nei terreni a grana fina).
D	*Depositi di terreni a grana grossa scarsamente addensati o di terreni a grana fina scarsamente consistenti*, con spessori superiori a 30 m, caratterizzati da un graduale miglioramento delle proprietà meccaniche con la profondità e da valori di $V_{s,30}$ inferiori a 180 m/s (ovvero $N_{SPT,30} < 15$ nei terreni a grana grossa e $c_{u,30} < 70$ kPa nei terreni a grana fina).
E	*Terreni dei sottosuoli di tipo C o D per spessore non superiore a 20 m*, posti sul substrato di riferimento (con $V_s > 800$ m/s).

La velocità equivalente delle onde di taglio $V_{s,30}$ è definita dall'espressione

$$V_{S,30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_{S,i}}} \text{ [m/s].}$$

Site effects and Italian code



S= fattore di amplificazione
T_B, T_C, T_D = periodo che separano i diversi rami dello spettro

amplificazione del terreno

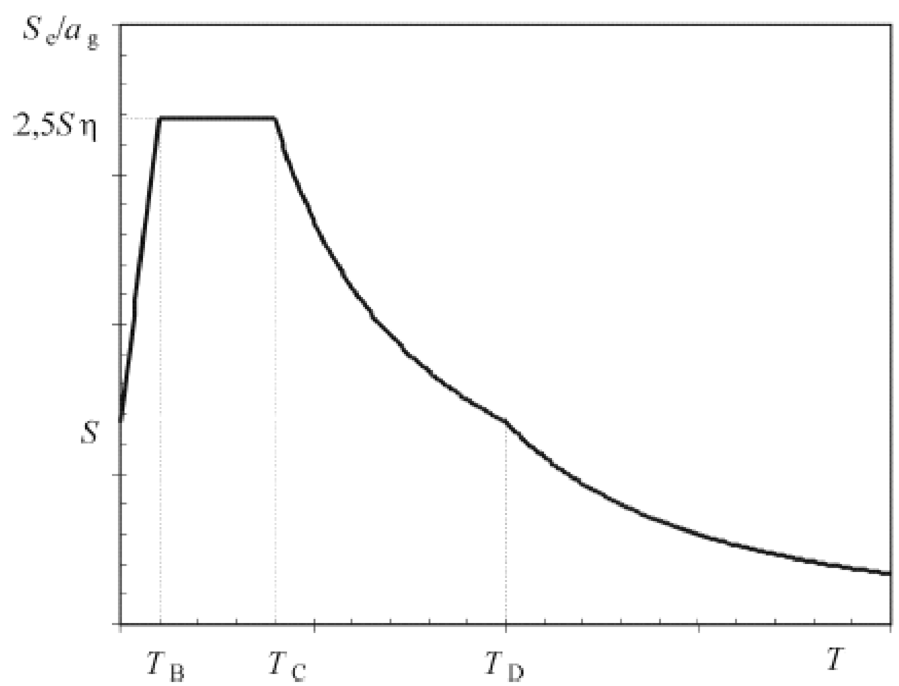
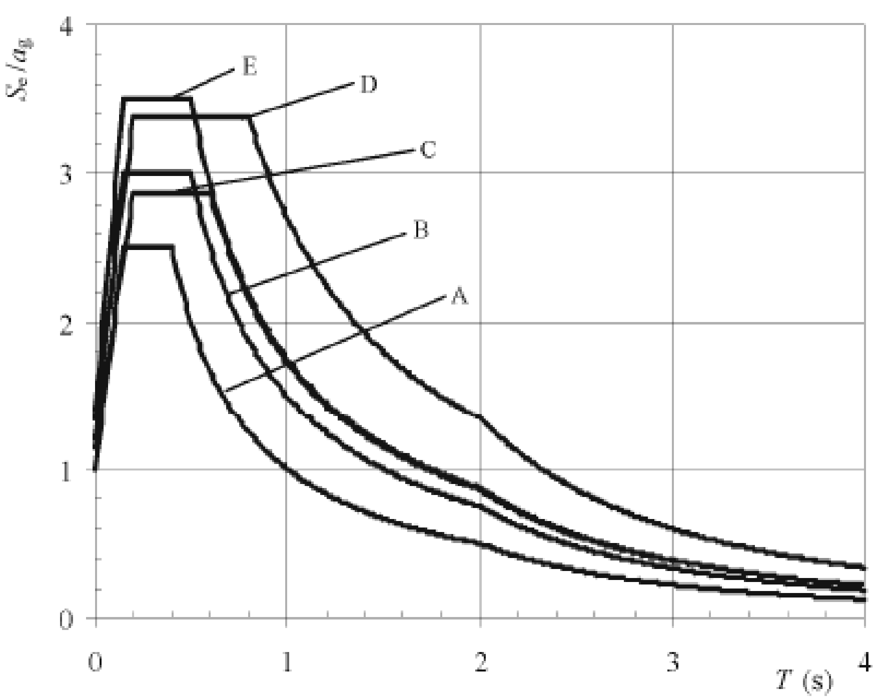


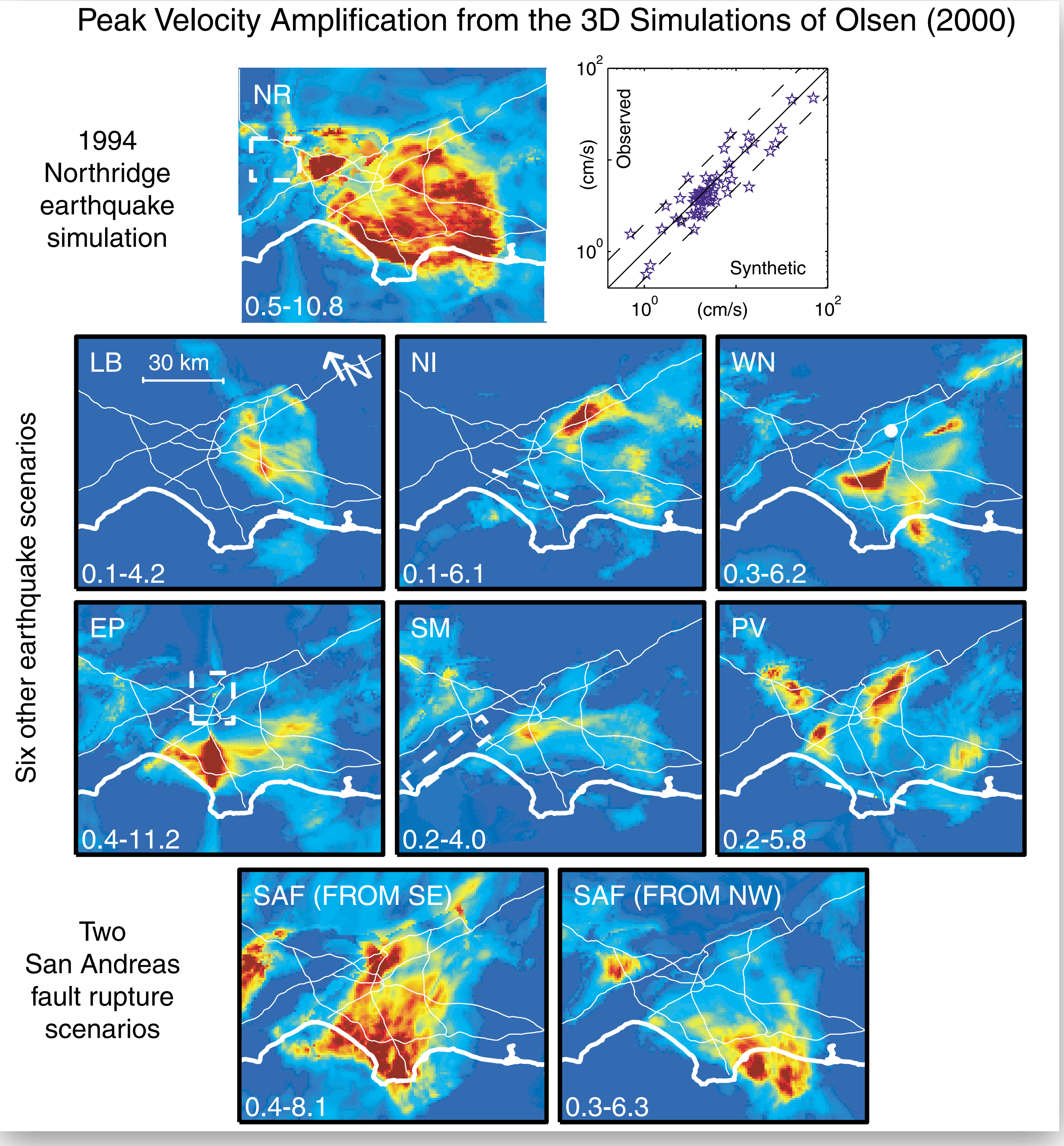
Figure 3.1: Shape of the elastic response spectrum



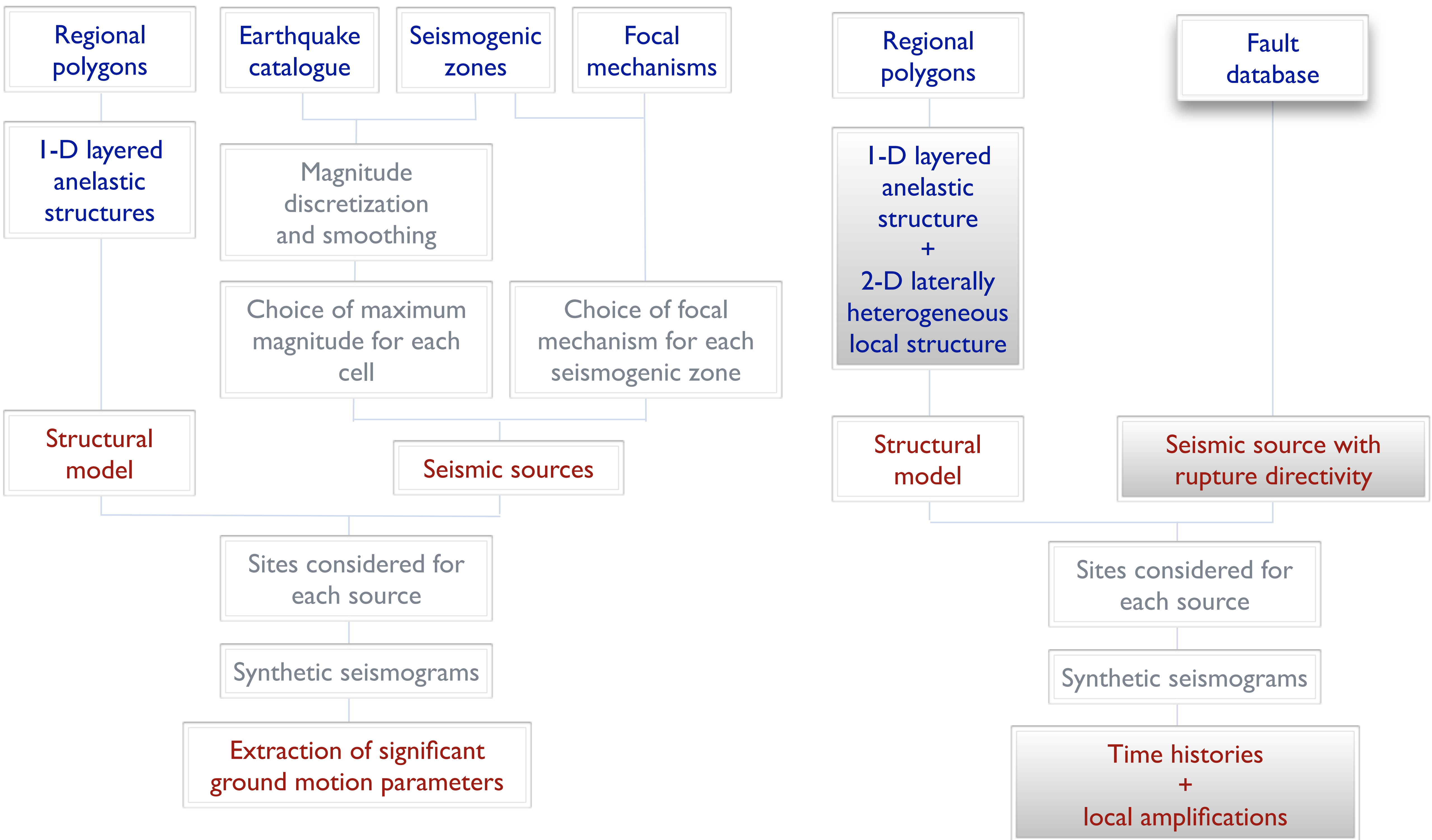
Amplification patterns...

....may vary greatly among the earthquake scenarios, considering different source locations (and rupture ...)

SCEC Phase 3 Report



Regional & Local scale → Local scale (2D)



Introduction - Local scale

- Synthetic seismograms along selected profiles
- Laterally heterogeneous structural models
- Detailed source models
- Cutoff frequency up to 10 Hz
- Time series, amplification maps

Introduction - Methodology

- Regional scale: modal summation
- Local scale: hybrid methodology (modal summation + finite differences)

Methodology - Modal summation

- Displacement generated by a double-couple in layered half-space (Panza, 1985, Florsch et al 1991)

$$u_y^L(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x \text{-} \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^L(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_y(z,\omega)\right)}{\sqrt{v_m I_m}}$$

$$u_x^R(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x \text{-} \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^R(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_x(z,\omega)\right)}{\sqrt{v_m I_m}}$$

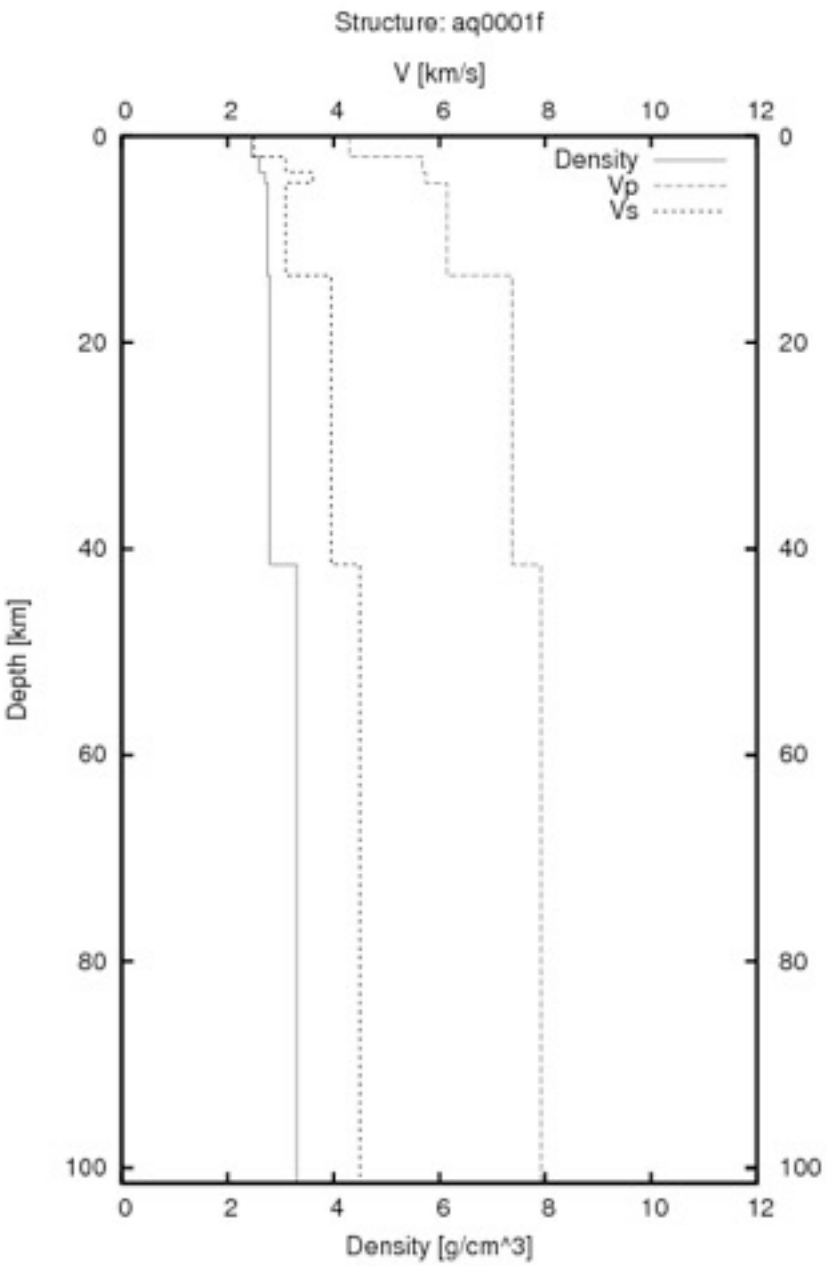
$$u_z^R(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x \text{-} \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^R(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_z(z,\omega)\right)}{\sqrt{v_m I_m}}$$

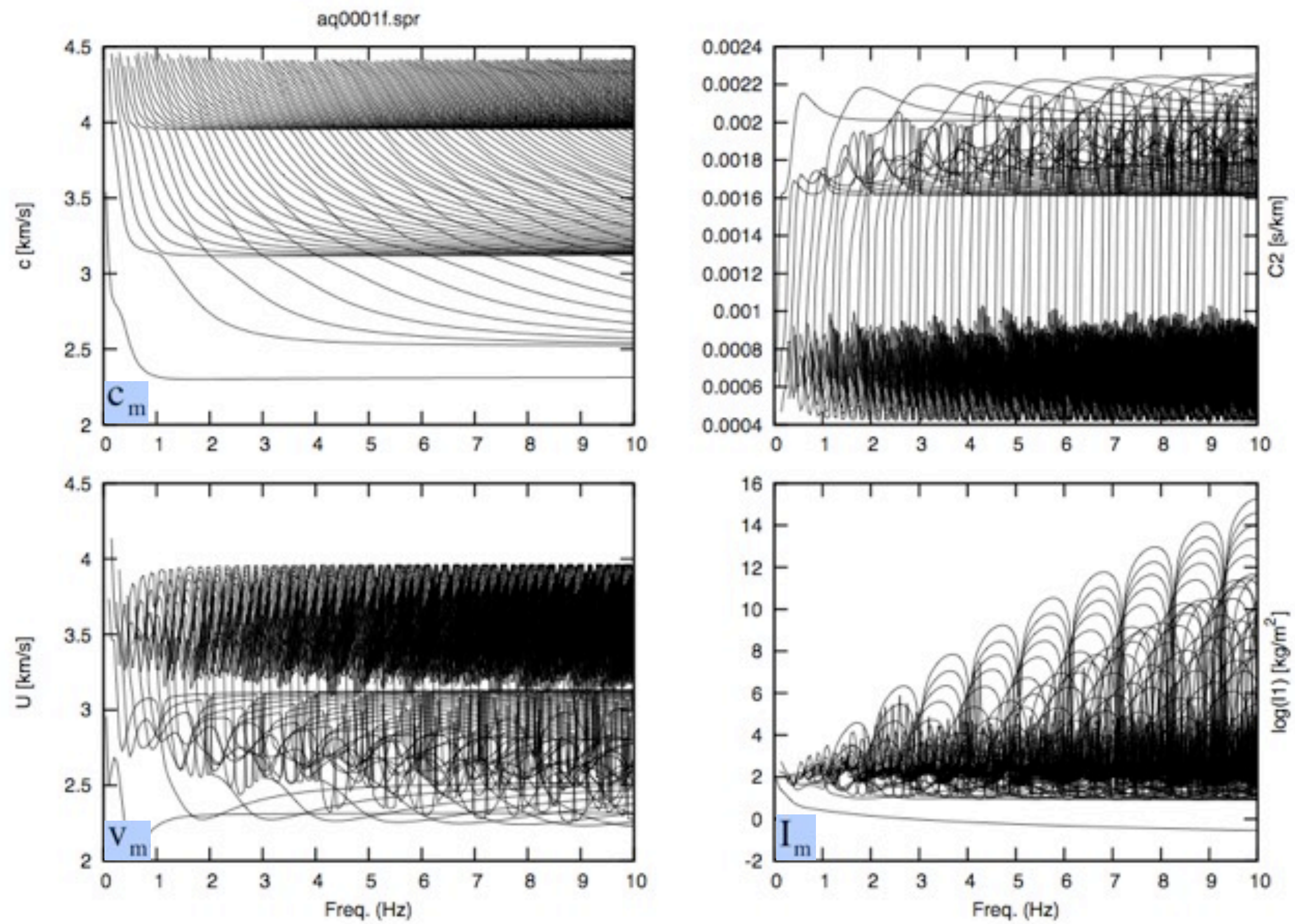
source (yellow) · propagation (blue) · site (pink)

Methodology - Modal summation

- Examples of structural quantities

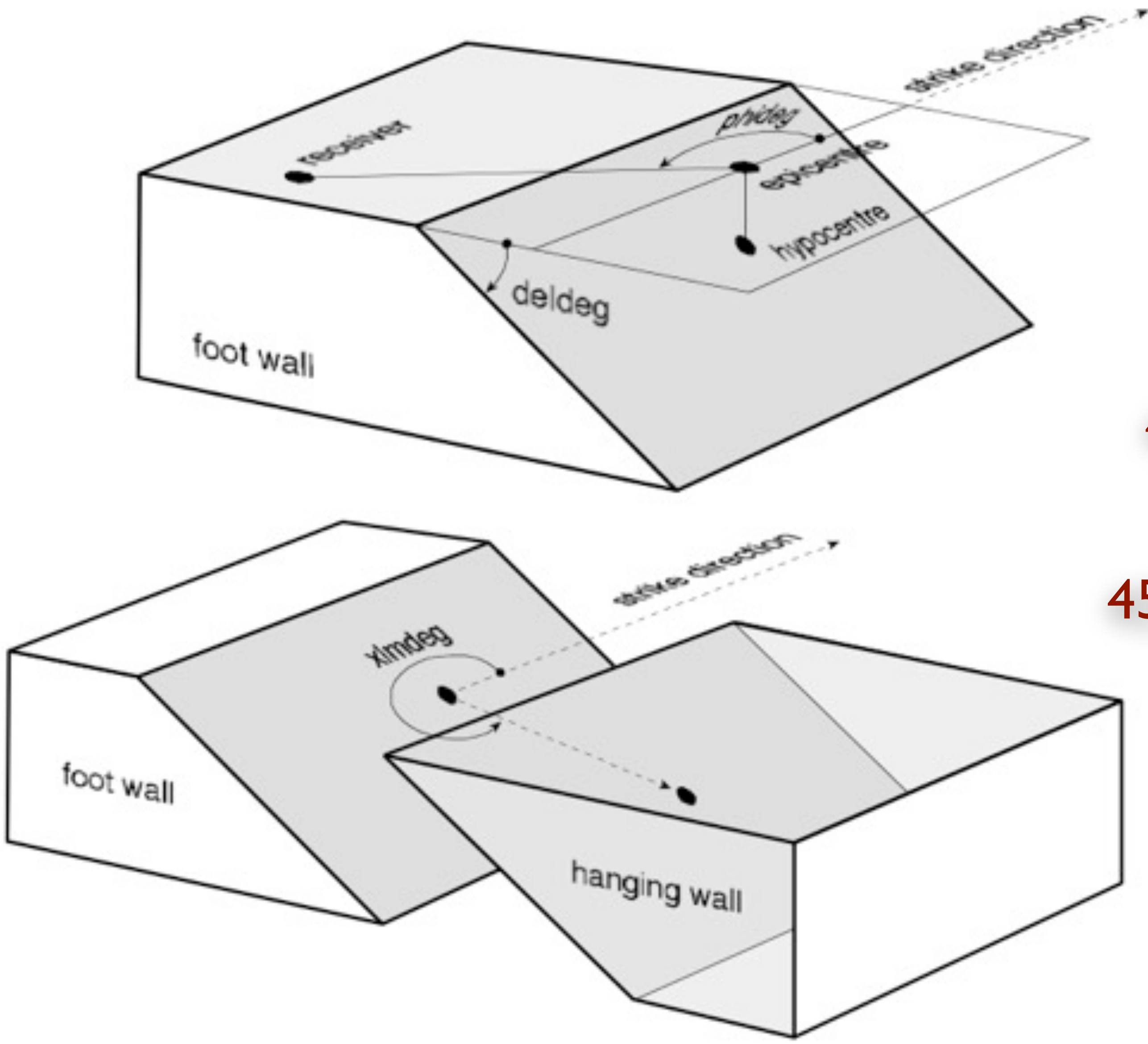
$$\sqrt{c_m v_m I_m} \qquad \sqrt{v_m I_m}$$

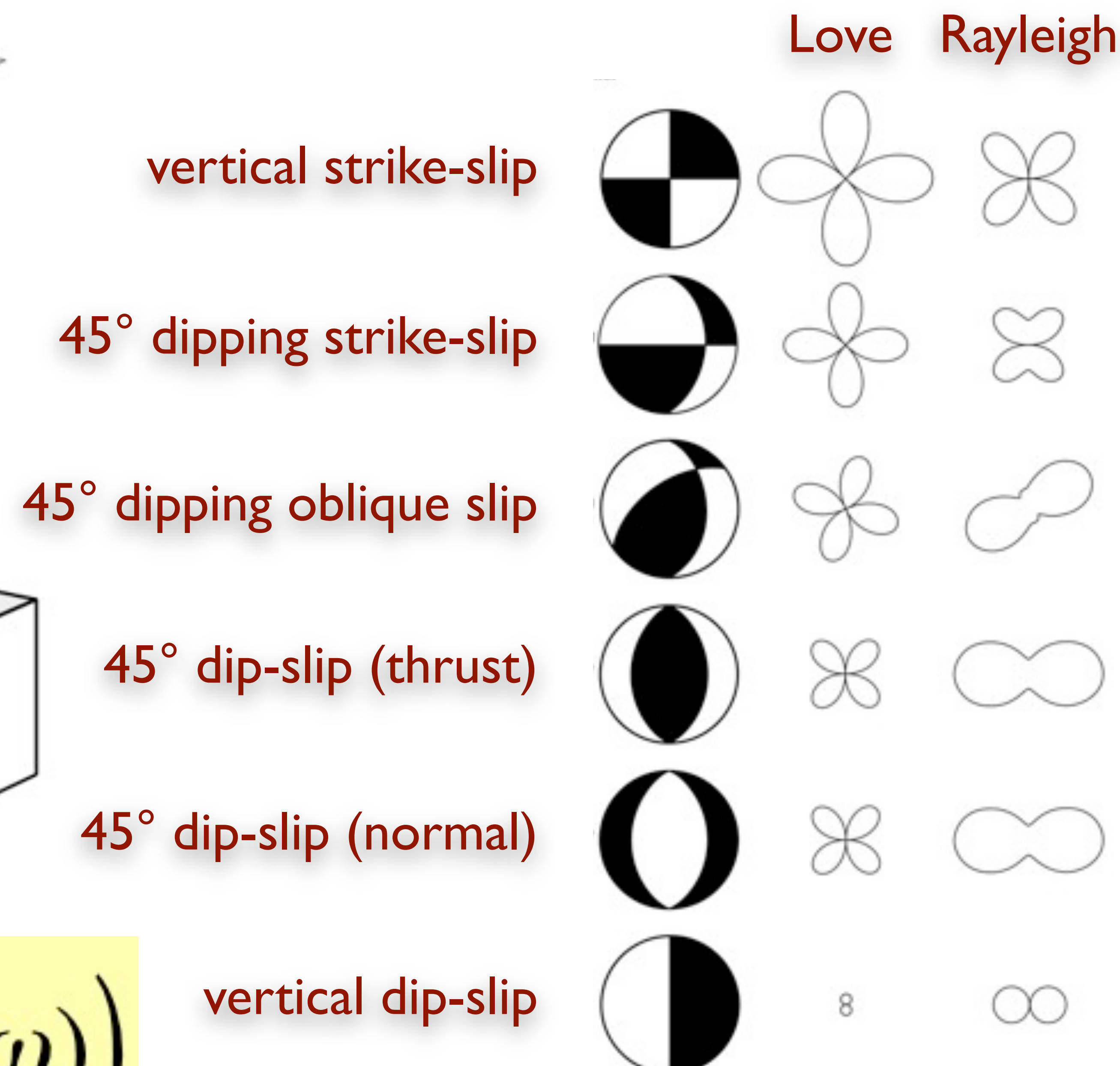




Methodology - Modal summation

- Source definition and radiation pattern

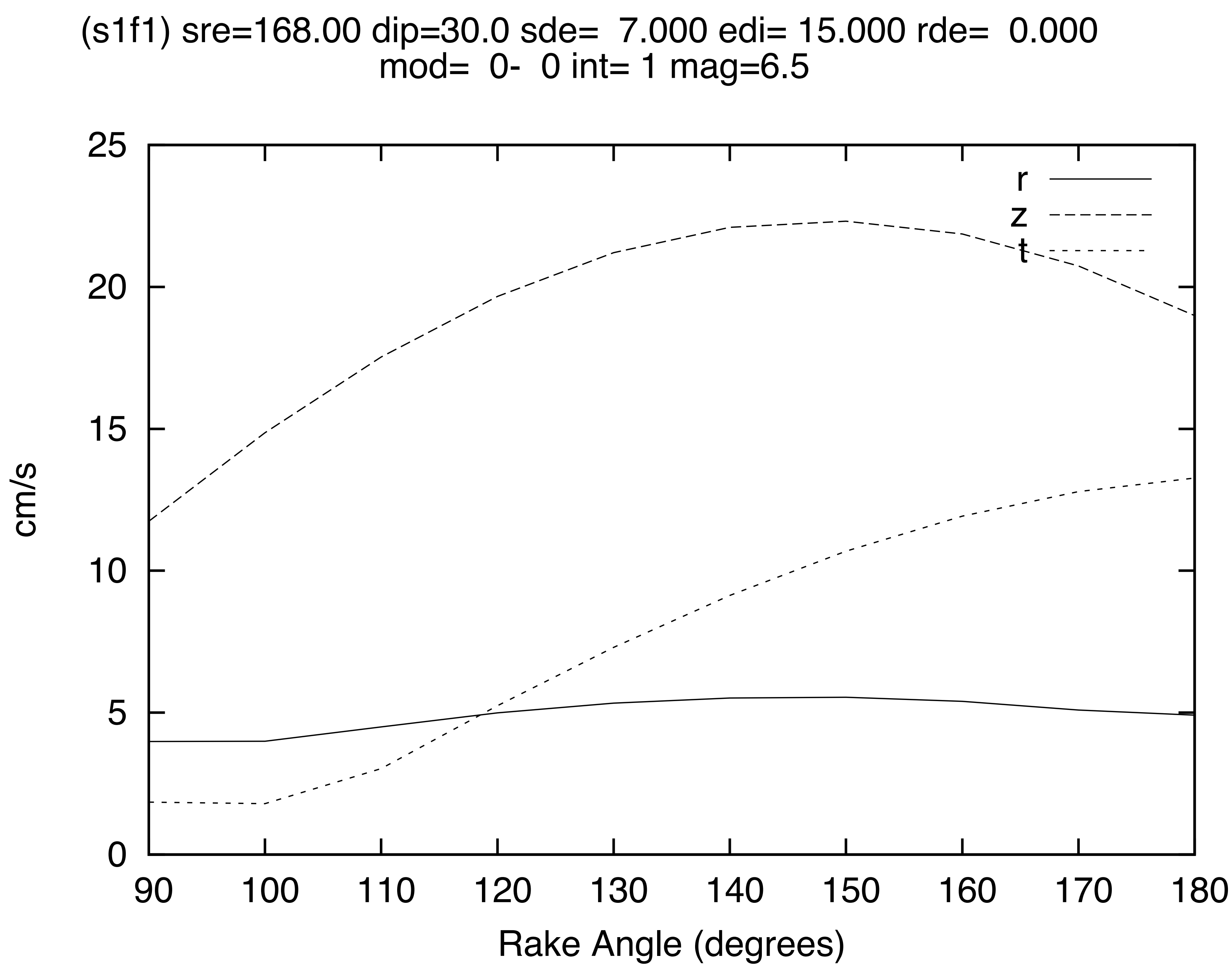




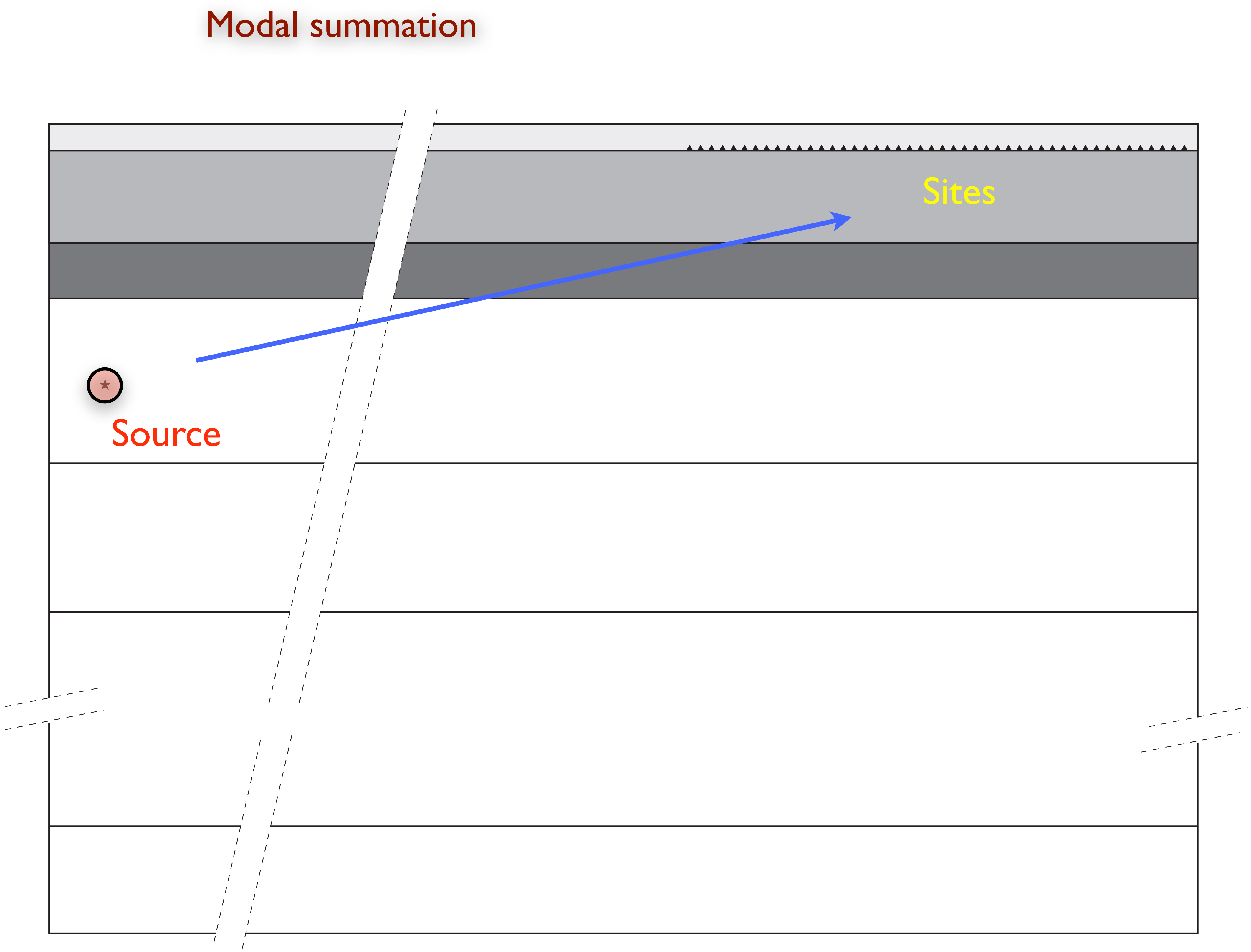
$$\left(\chi_m^L(h_s,\omega)\right) \quad \left(\chi_m^R(h_s,\omega)\right)$$

Methodology - Modal summation

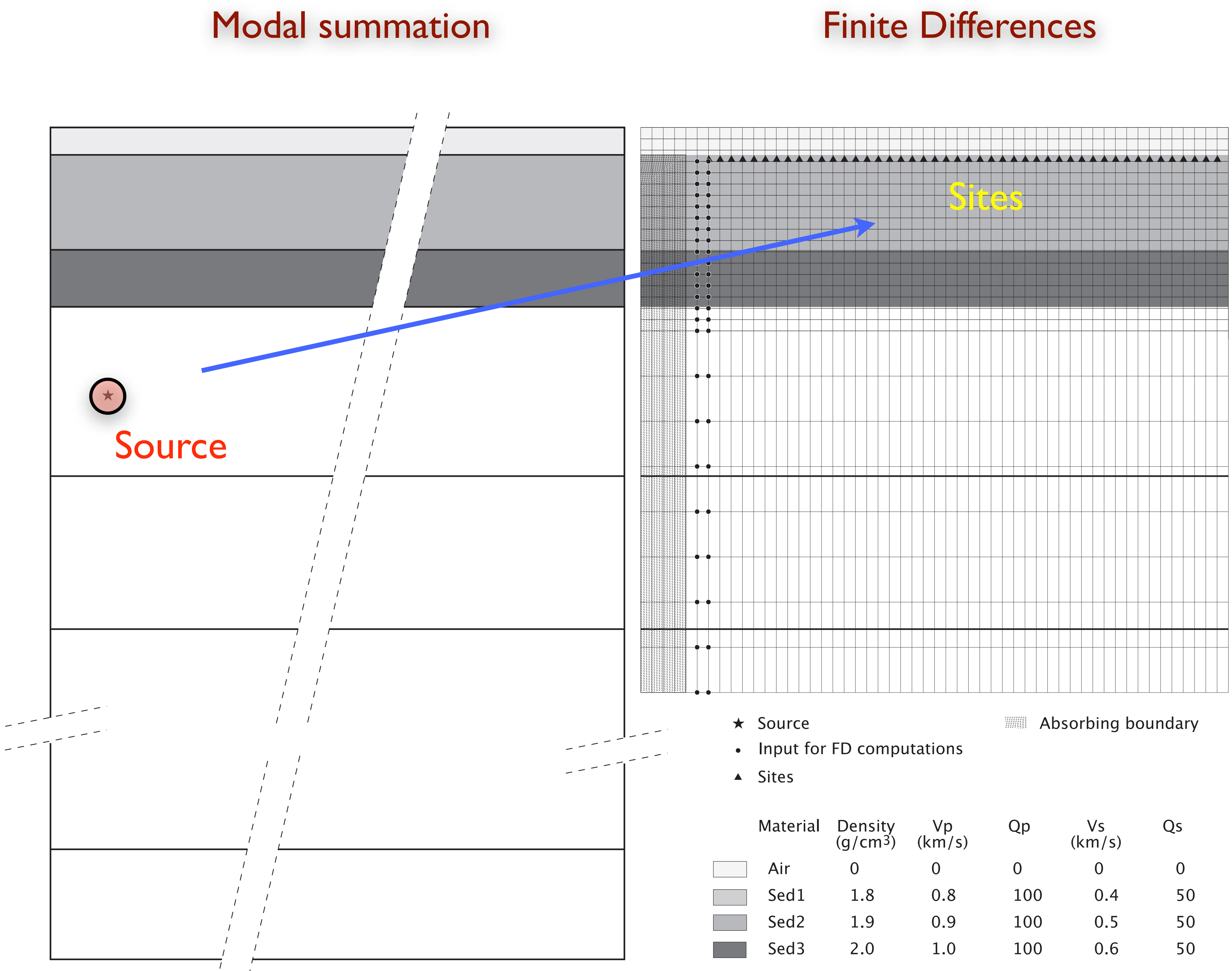
- 1D parametric tests: rake variation



Methodology - Modal summation (regional scale)



Methodology - Hybrid technique

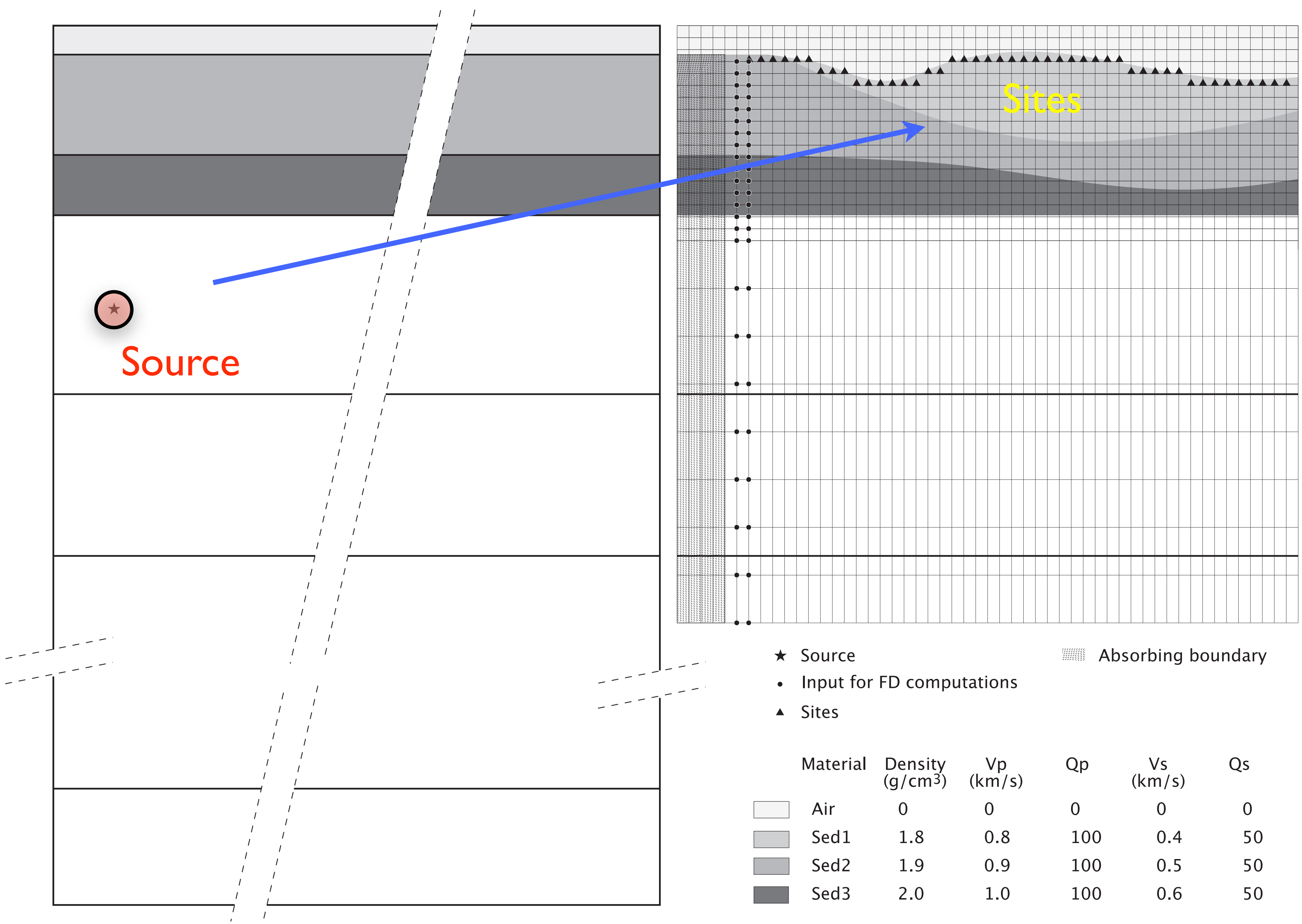


Material	Density (g/cm^3)	Vp (km/s)	Qp	Vs (km/s)	Qs
Air	0	0	0	0	0
Sed1	1.8	0.8	100	0.4	50
Sed2	1.9	0.9	100	0.5	50
Sed3	2.0	1.0	100	0.6	50

Methodology - Hybrid technique (local scale)

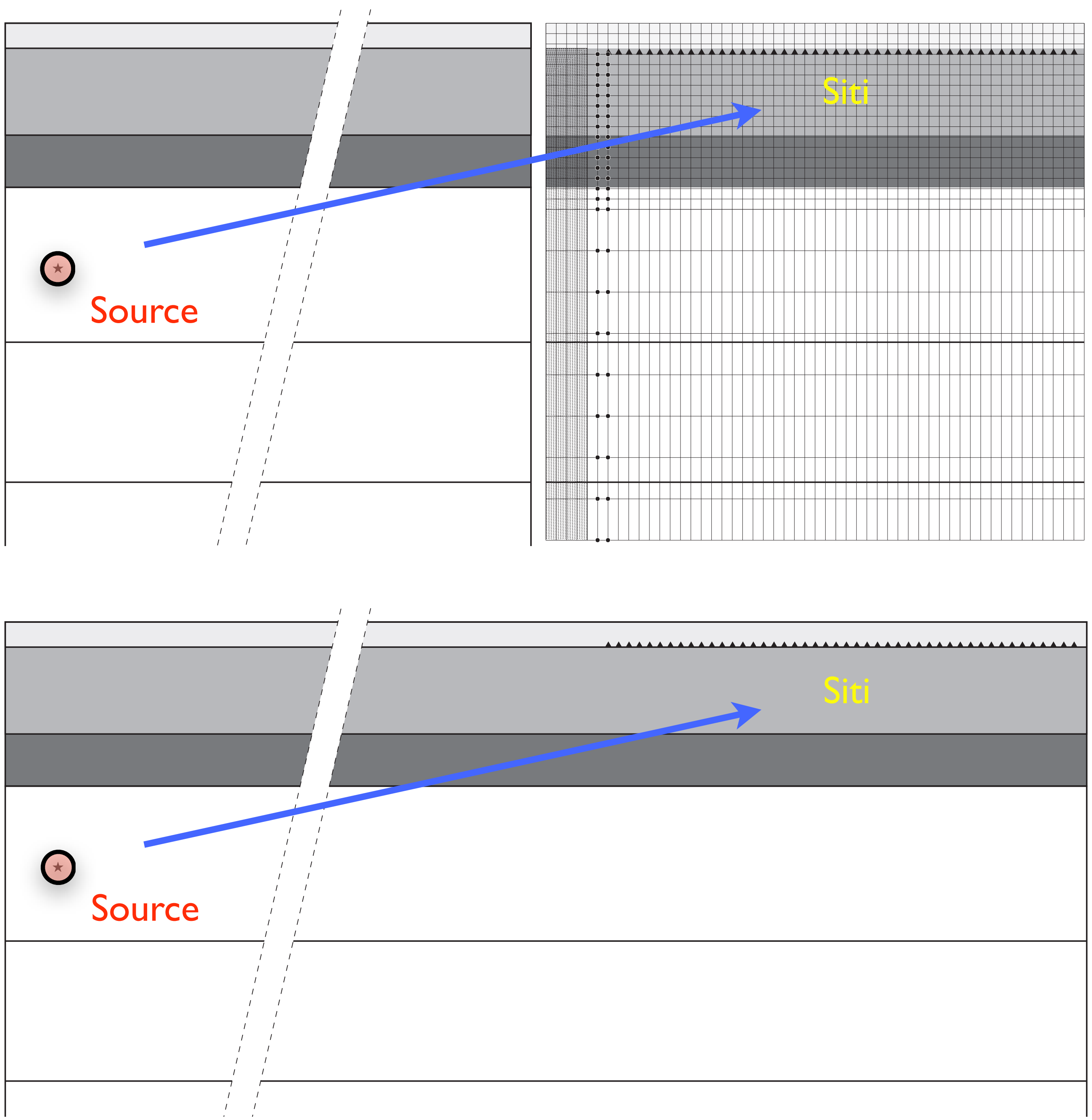
Modal summation

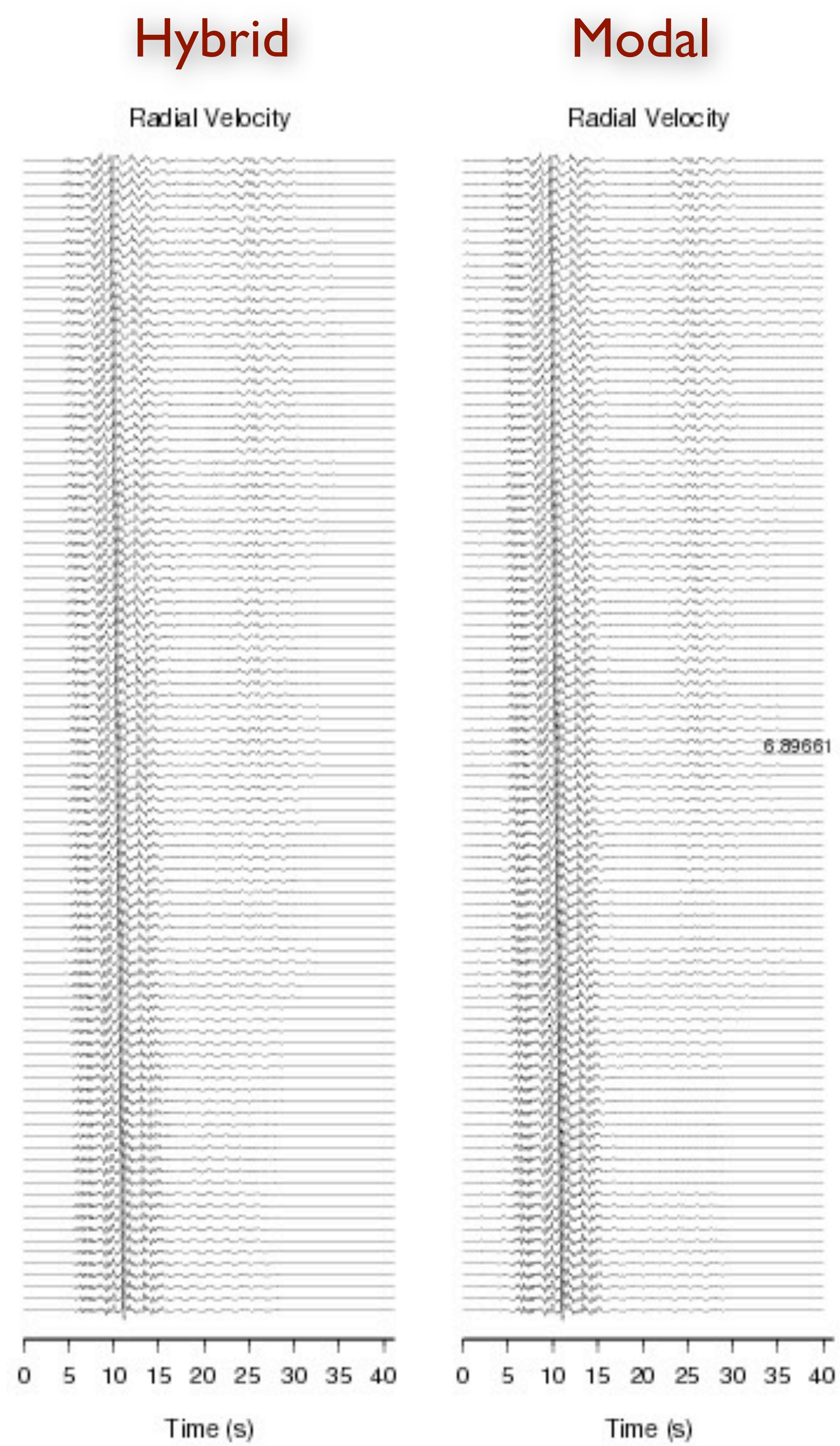
Finite Differences



Methodology - Hybrid method

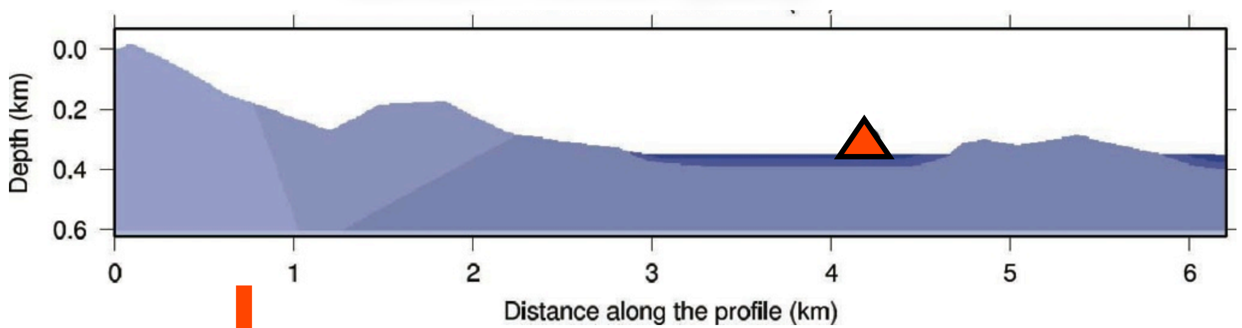
Quality test





Local Scale - Response Spectra Ratio

Local Model (2D)

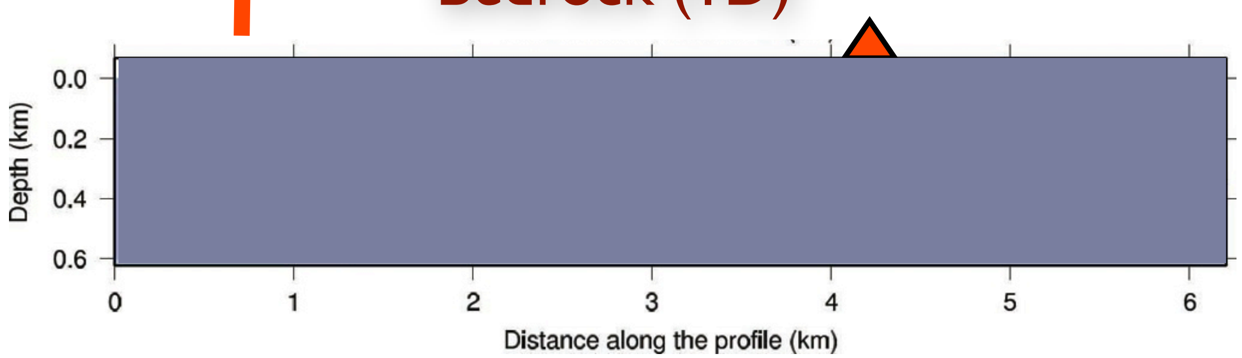


2D seismogram → 2D response spectra

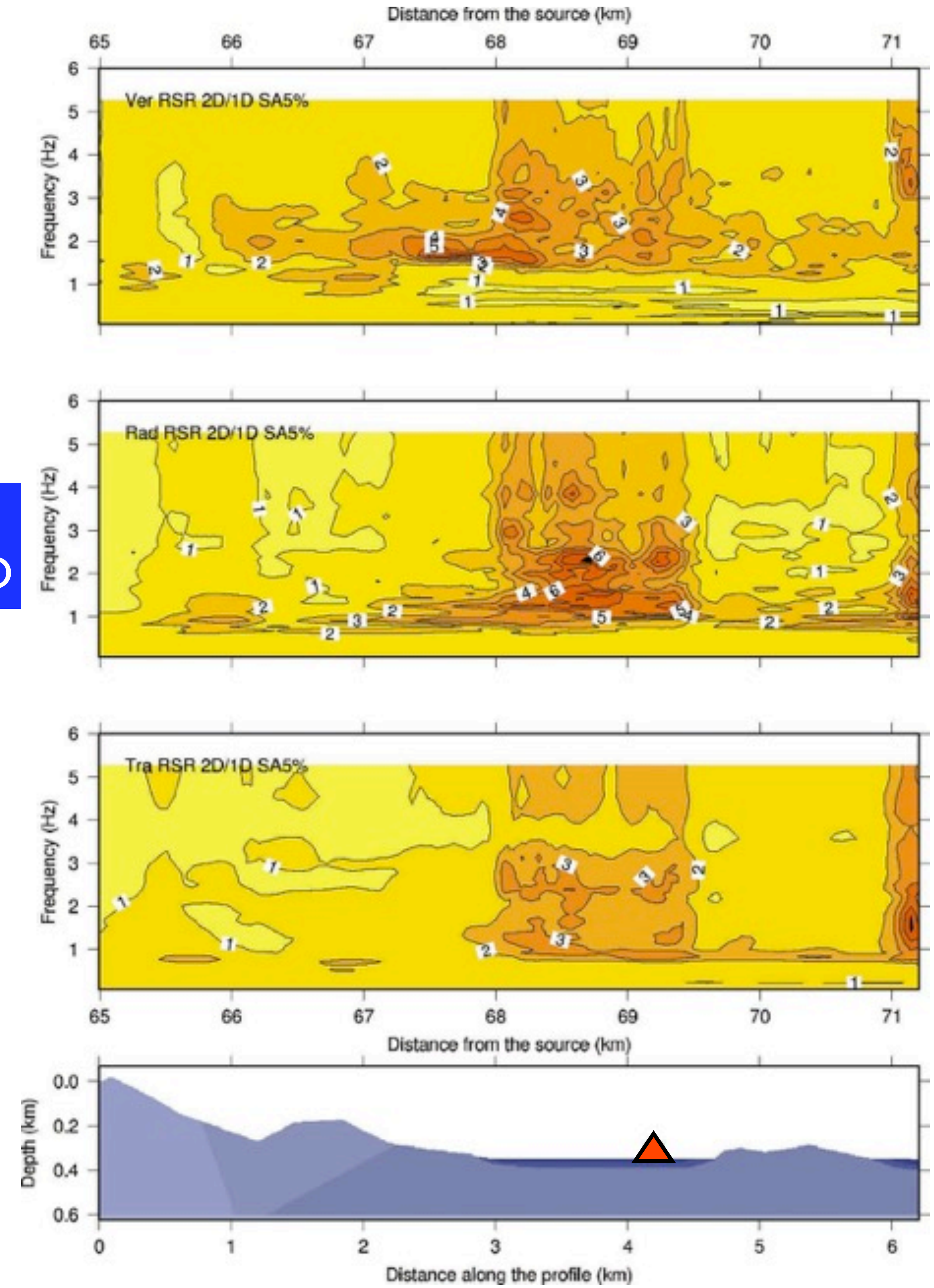
1D seismogram → 1D response spectra

→ RSR 2D/1D

Bedrock (1D)

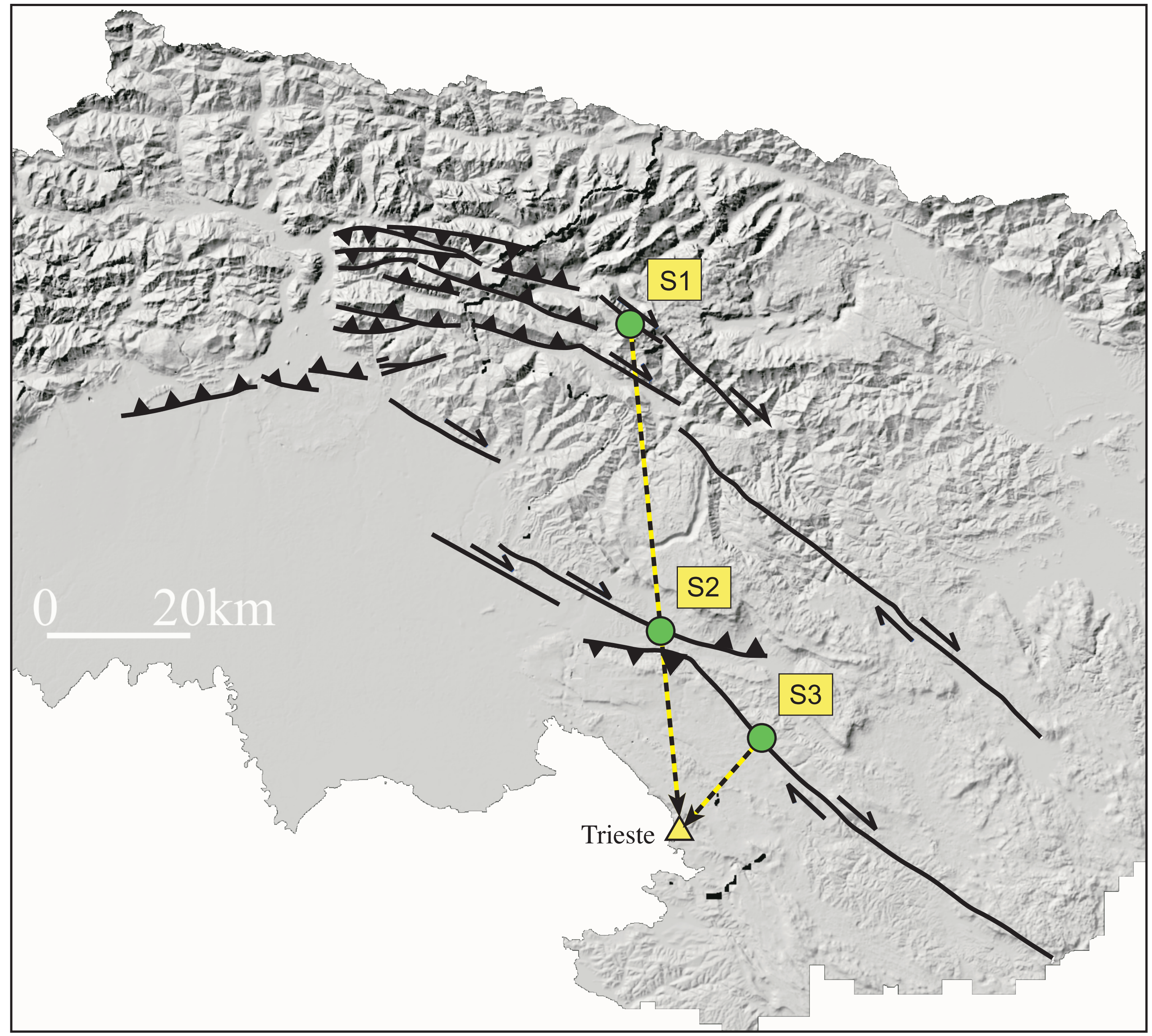


Site effects in Trieste city centre may cause a significant amplification (up to 5 times at engineering relevant frequencies) of the seismic signal at bedrock, hence intensity may reach IX (MCS) or VIII (MSK).



Local Scale - Choice of Scenario Earthquakes

- Regional zonation
- Morphostructural analysis
- Active faults
- Earthquake prone areas

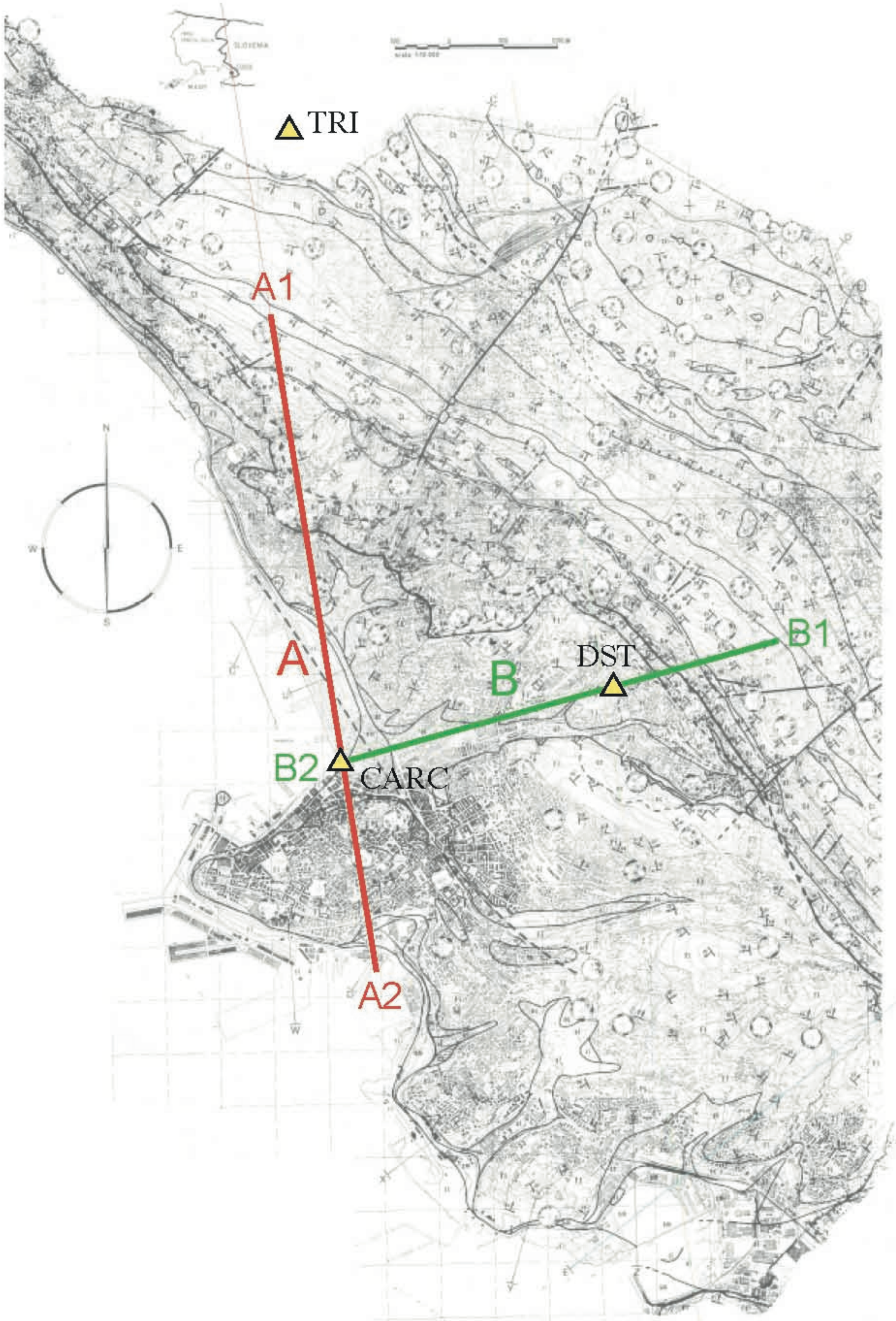


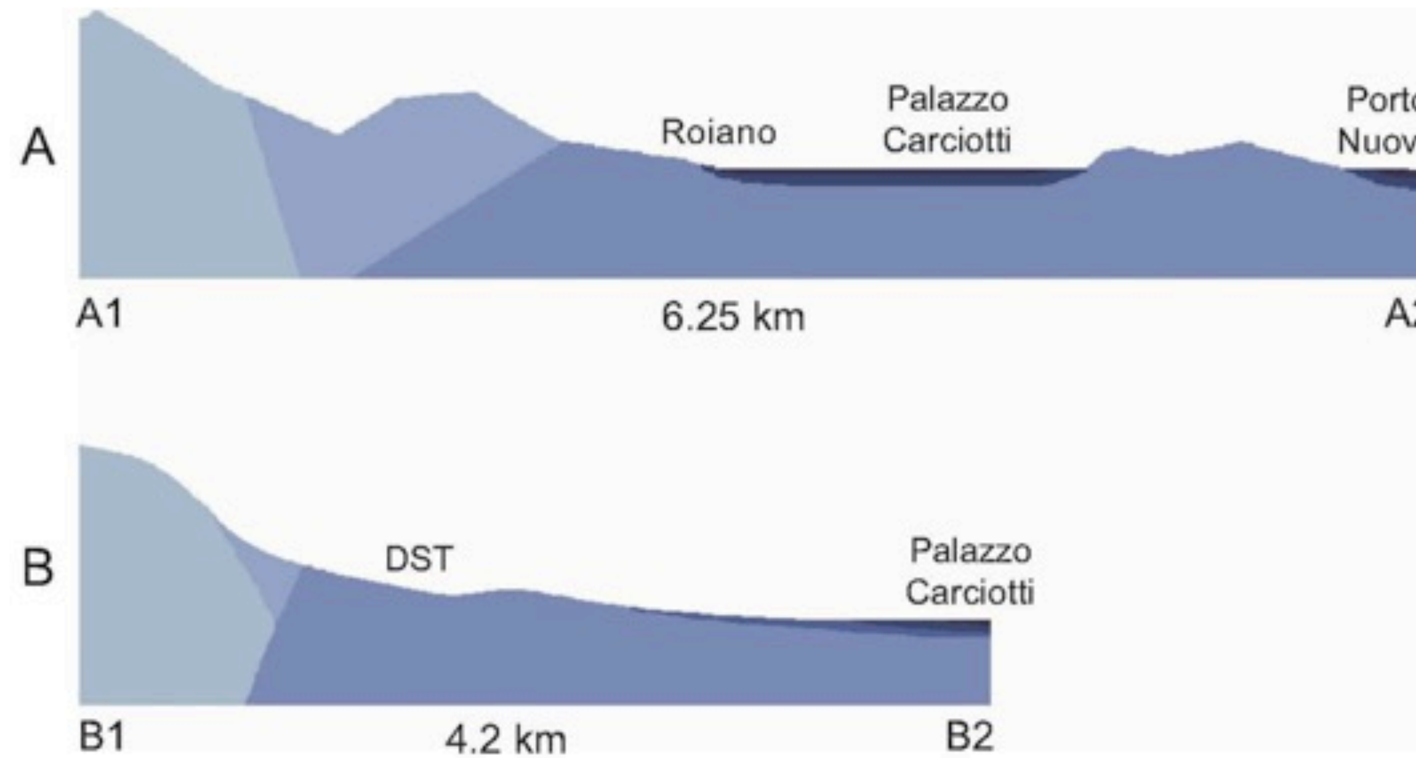
S1 in the Bovec zone
(65 km from Trieste)

S2 East of Gorizia
(30 km from Trieste)

S3 at 17 km from Trieste

Local Scale - Choice of Profiles

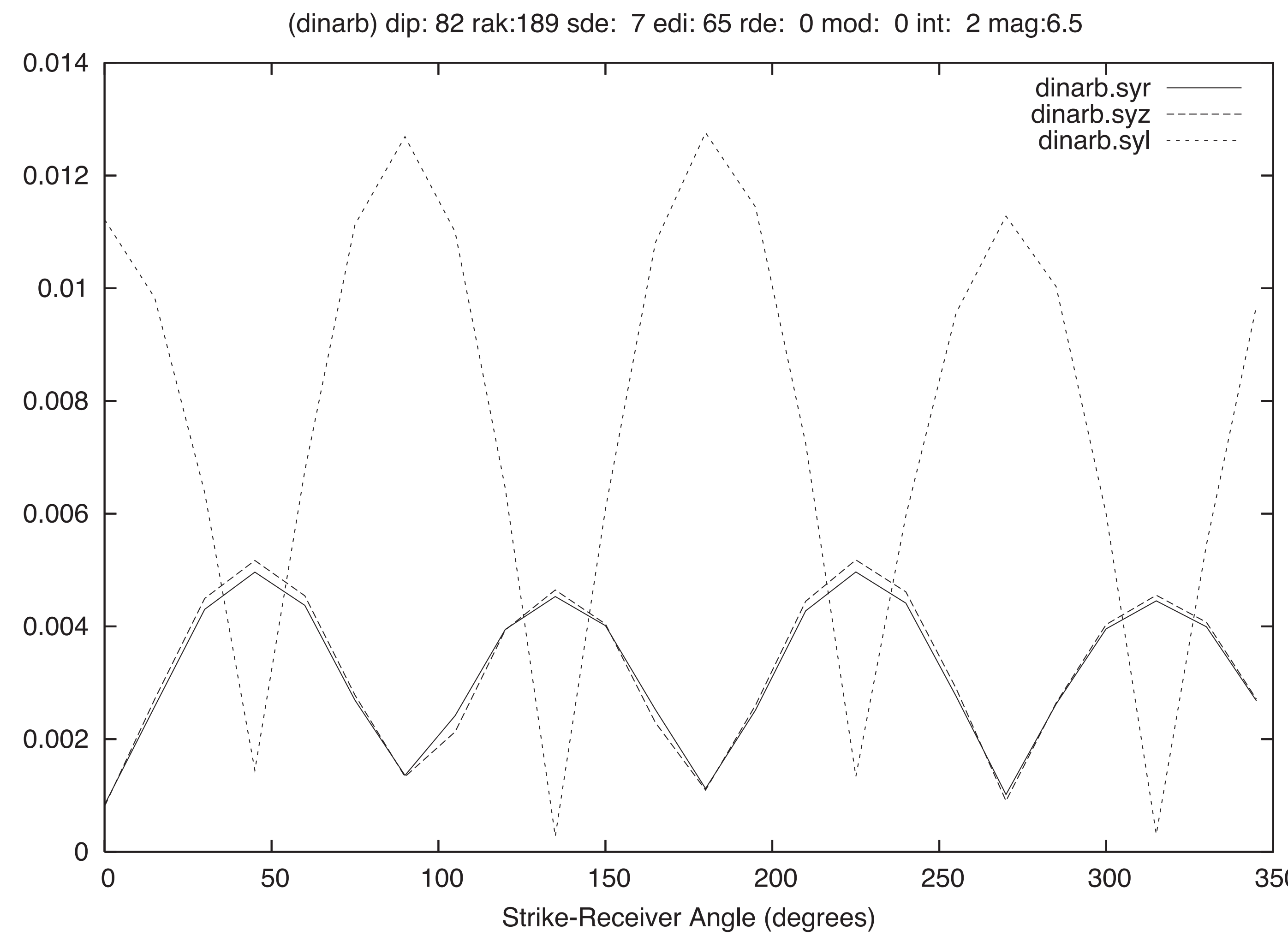




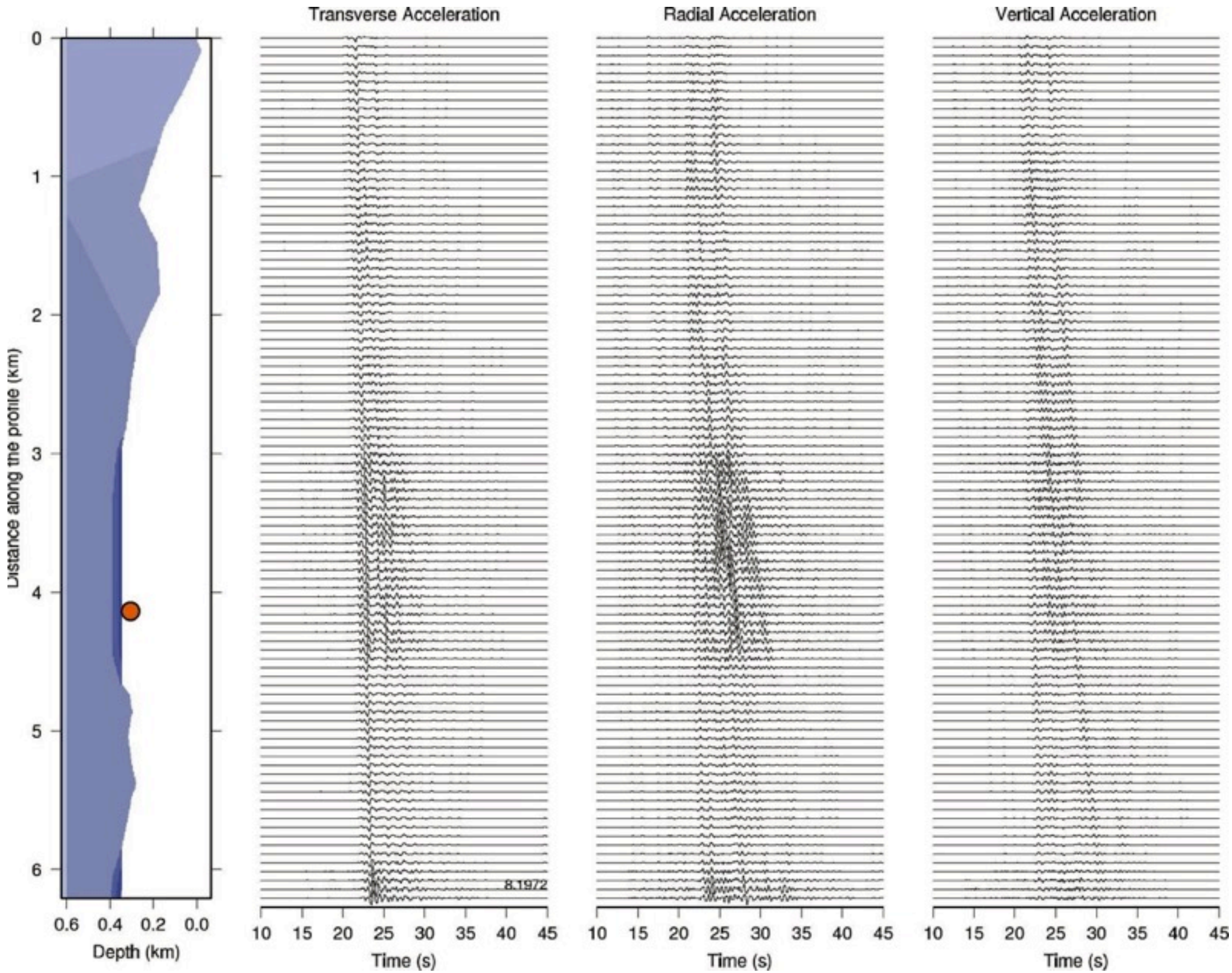
Litotipo	Densità (g/cm^3)	Vp (km/s)	Vs (km/s)	Qp	Qs
Riporti	1.8	0.4	0.2	30	15
Sed. Marini	1.9	0.8	0.4	40	20
Alluvioni	1.95	1.0	0.5	40	20
Flysch	2.0	1.8	1.0	100	50
Marne	2.0	1.9	1.1	200	100
Arenarie	2.1	2.0	1.2	200	100
Calcari	2.3	2.5	1.4	200	100

Local Scale - Preliminary Parametric Test

- Radiation Pattern
  - Source Depth
  - Epicentral Distance
  - ......



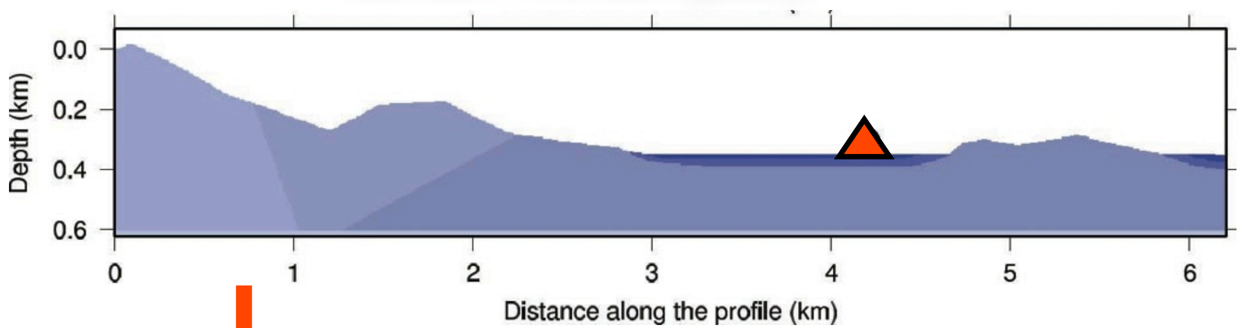
Local Scale - Synthetic Seismograms



Profile 1 - Bedrock "B" - Dist. 17 km - M=6.0

Local Scale - Response Spectra Ratio

Local Model (2D)



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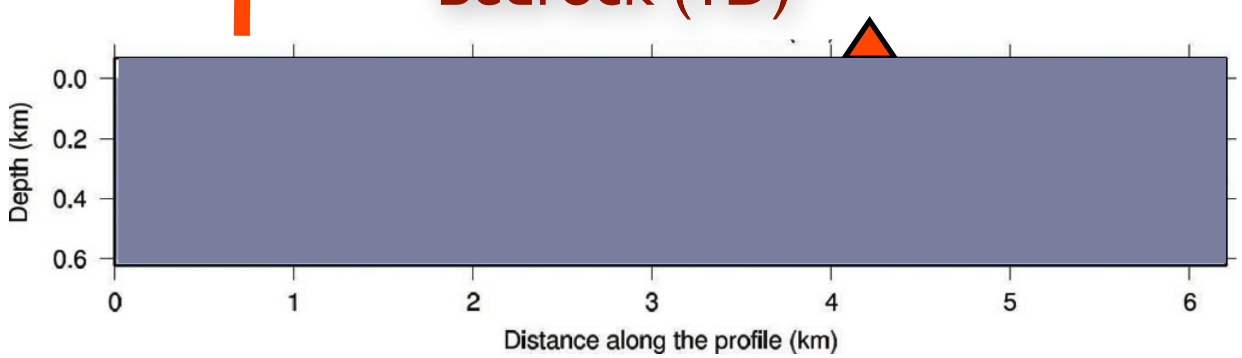
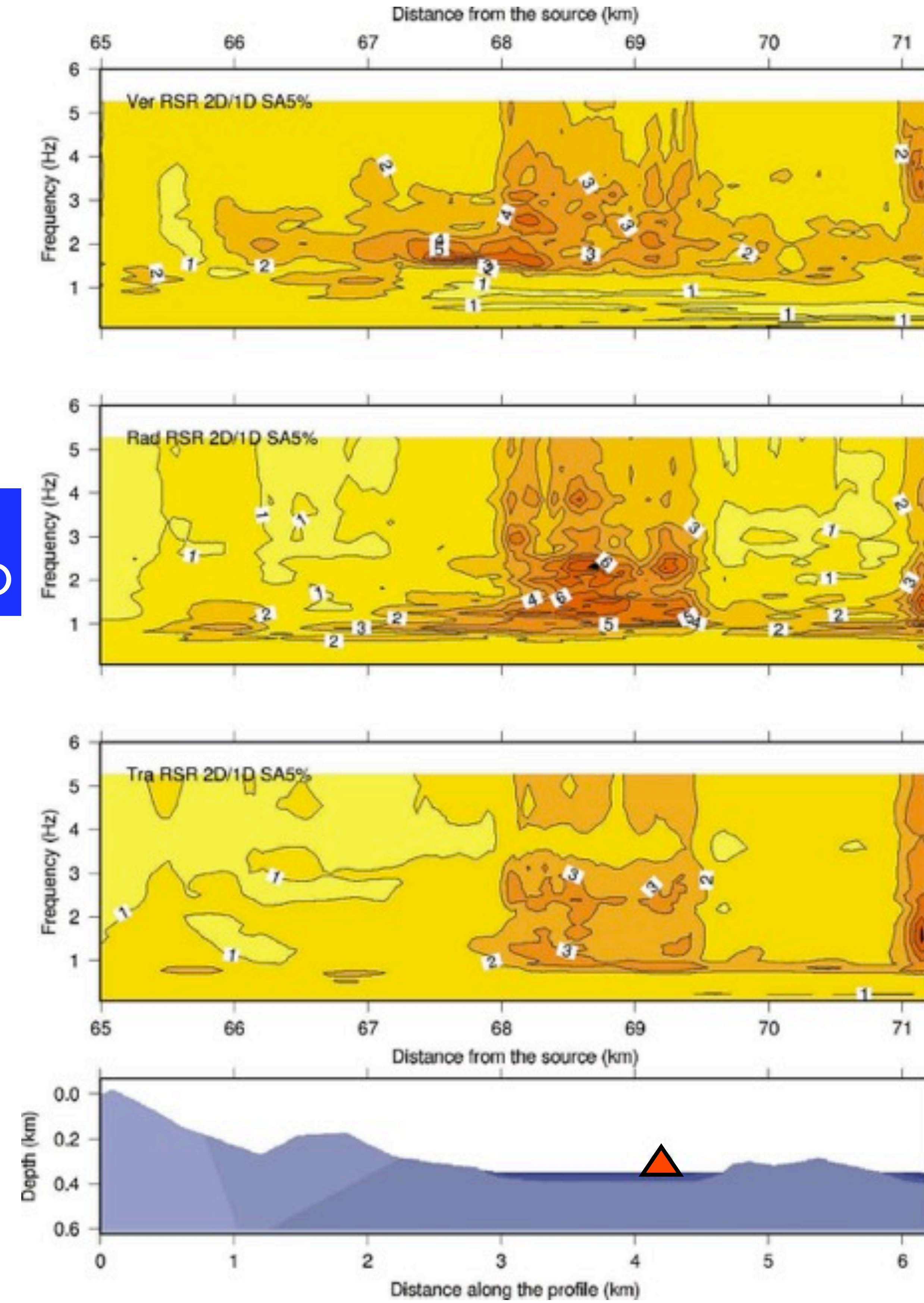
Bedrock (1D)





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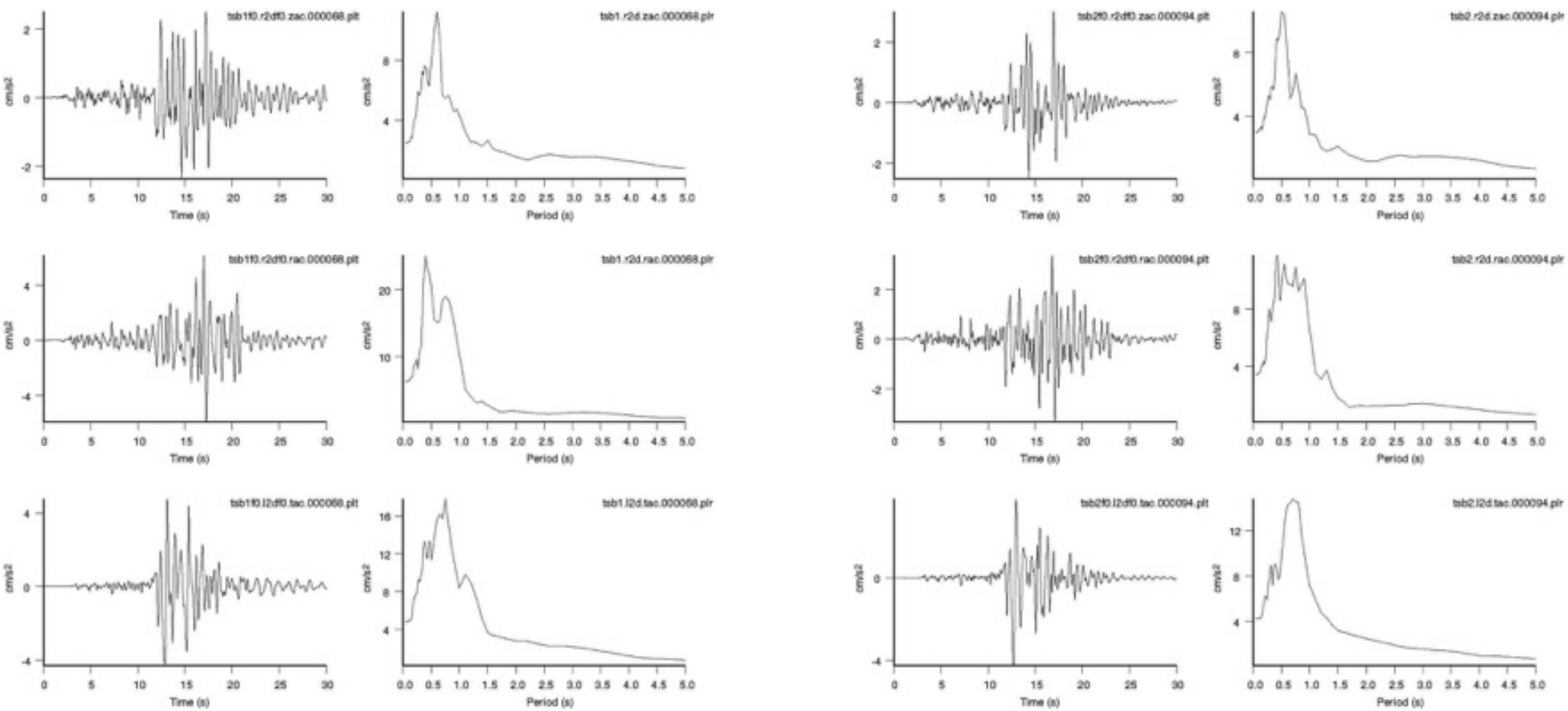
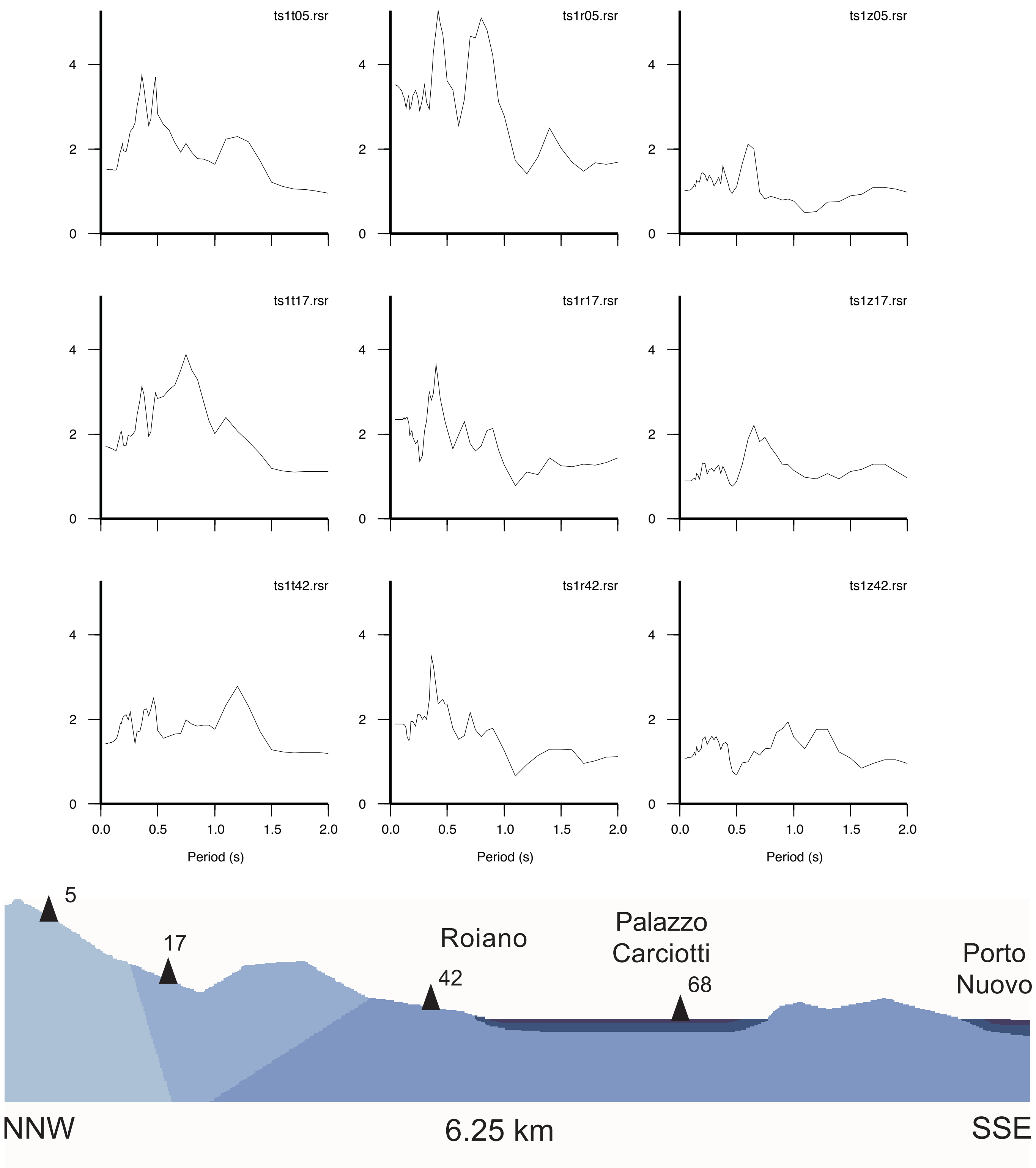
Local Scale - Response Spectra

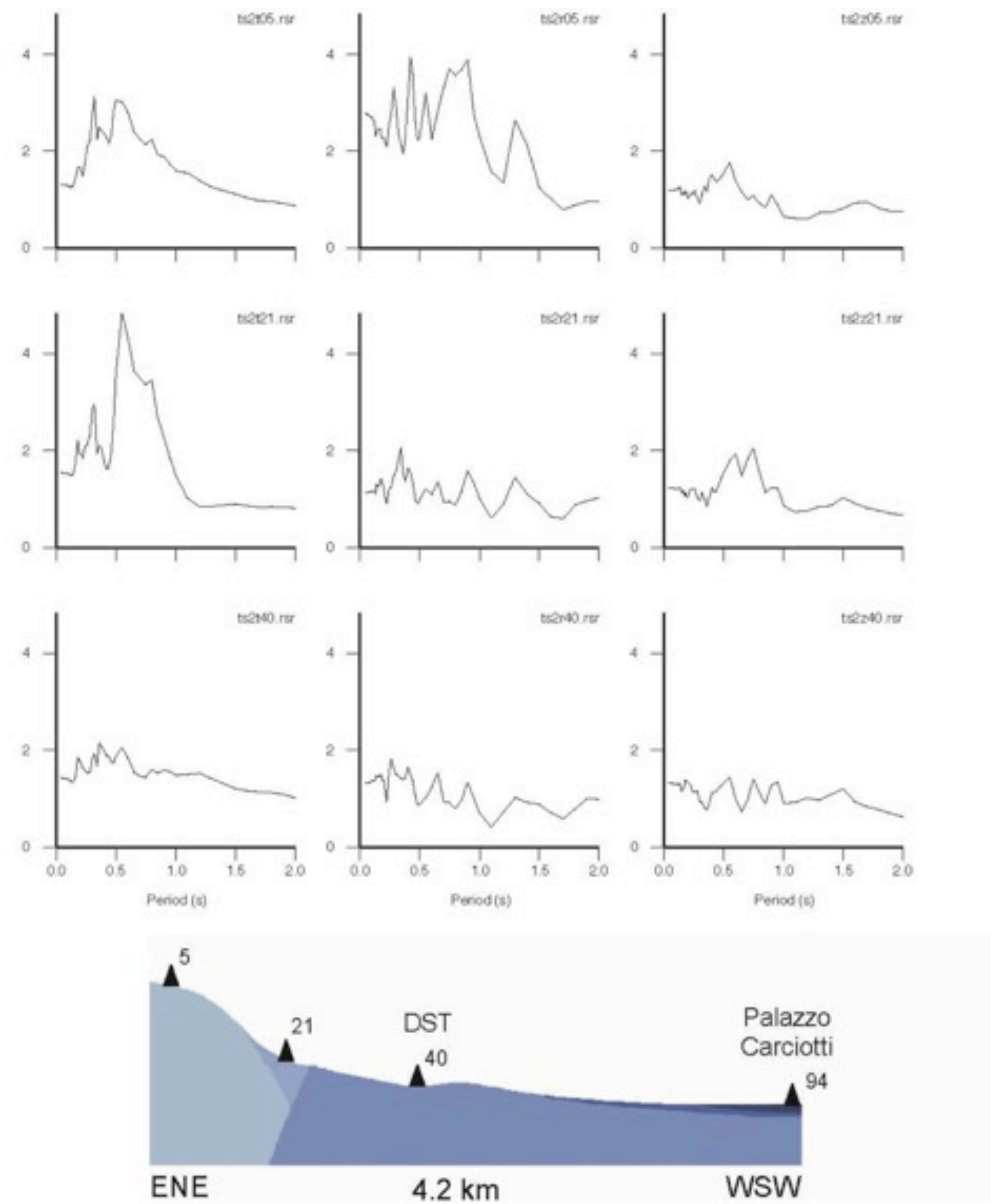
- Same site at the intersection of two profiles



Local Scale - Response Spectra Ratio

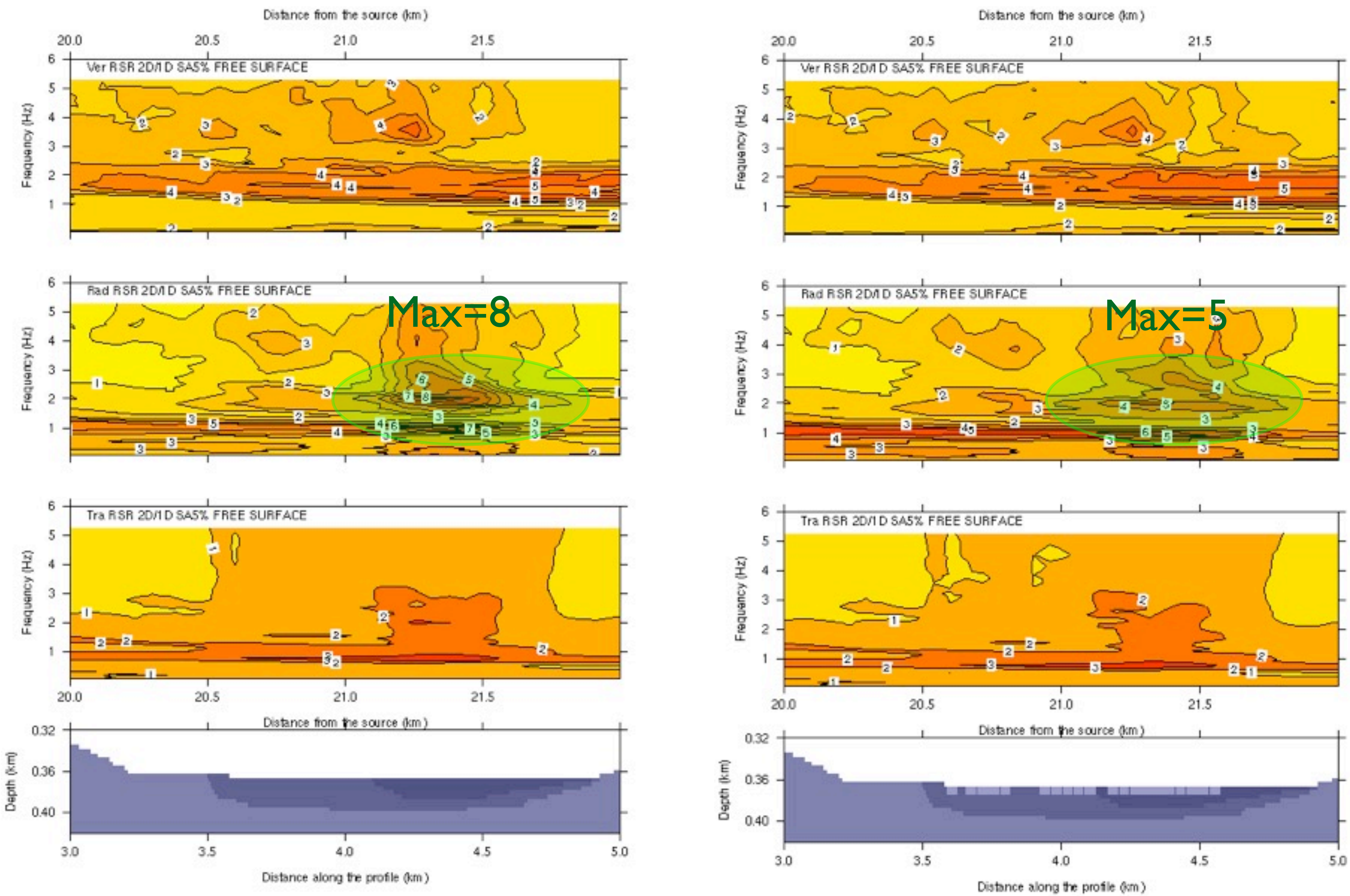
- Choice of reference site





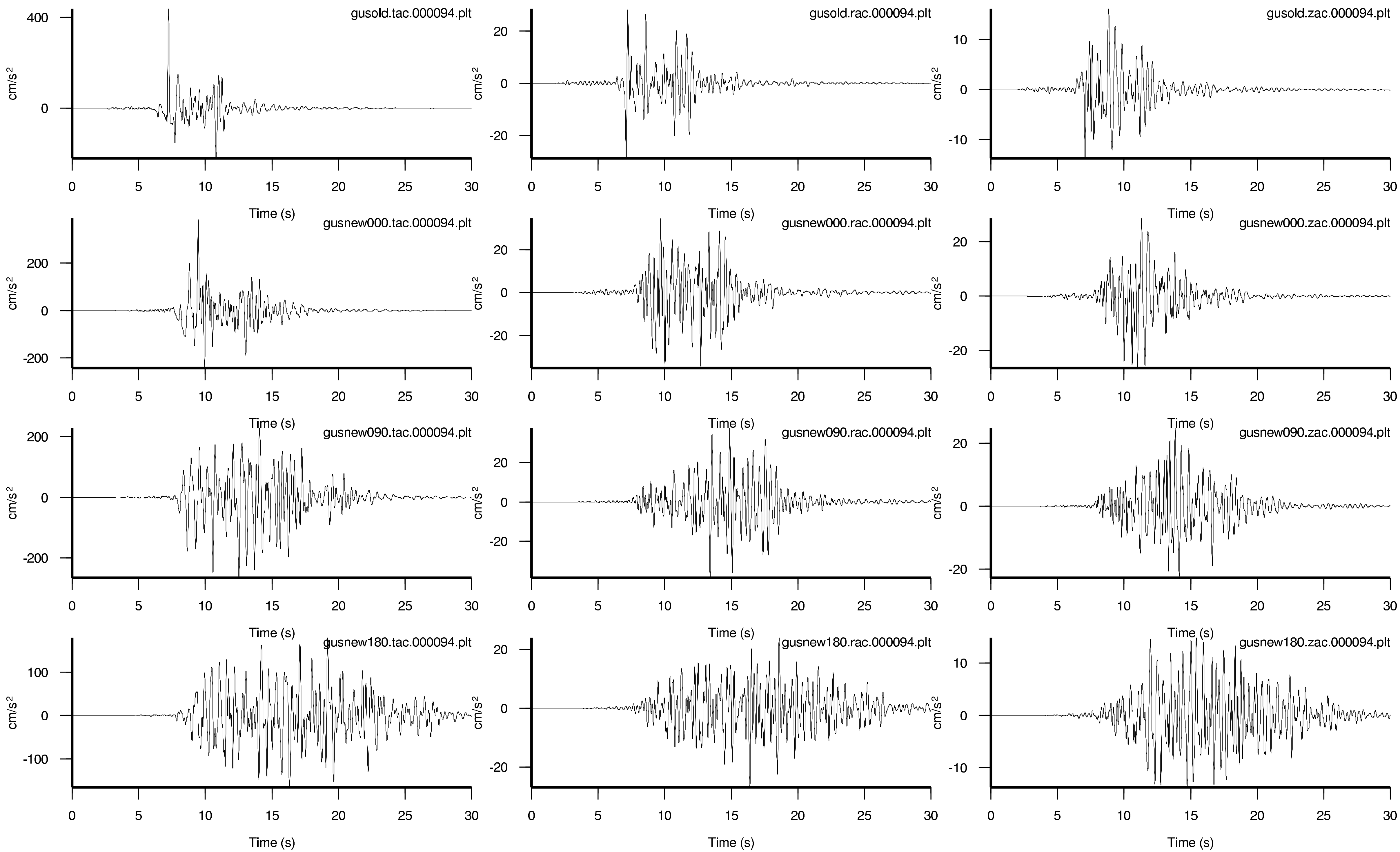
Local Scale - RSR with soil structure interaction

Rive - Dist. 17 km - M=6.0
Foundations and Amplifications (RSR 2D/1D)



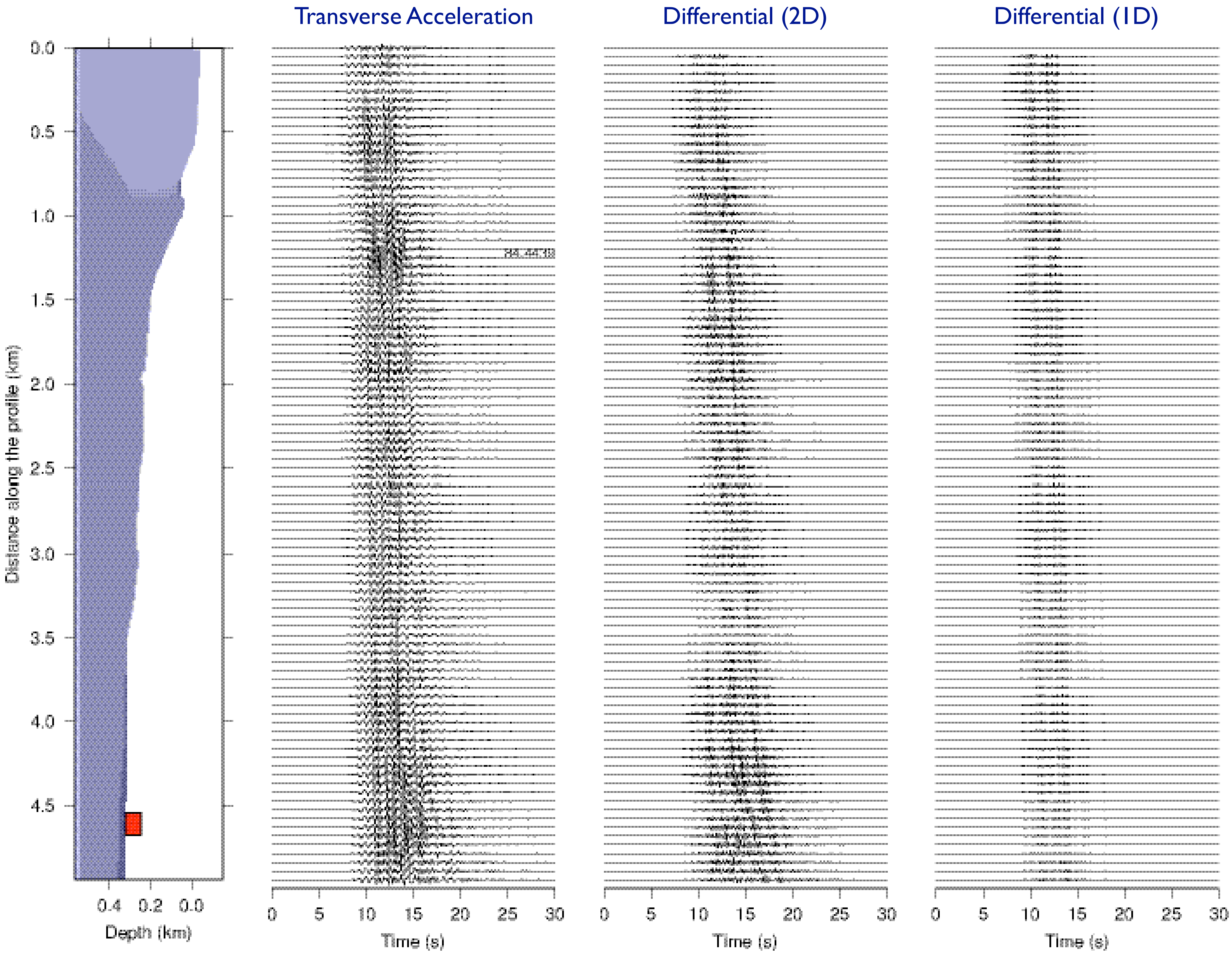
Local Scale - Source Model

- Seismic Source of finite dimension and complicated rupturing process



Local Scale - Differential Motion

- Significant for elongated structures (bridges, lifelines etc)



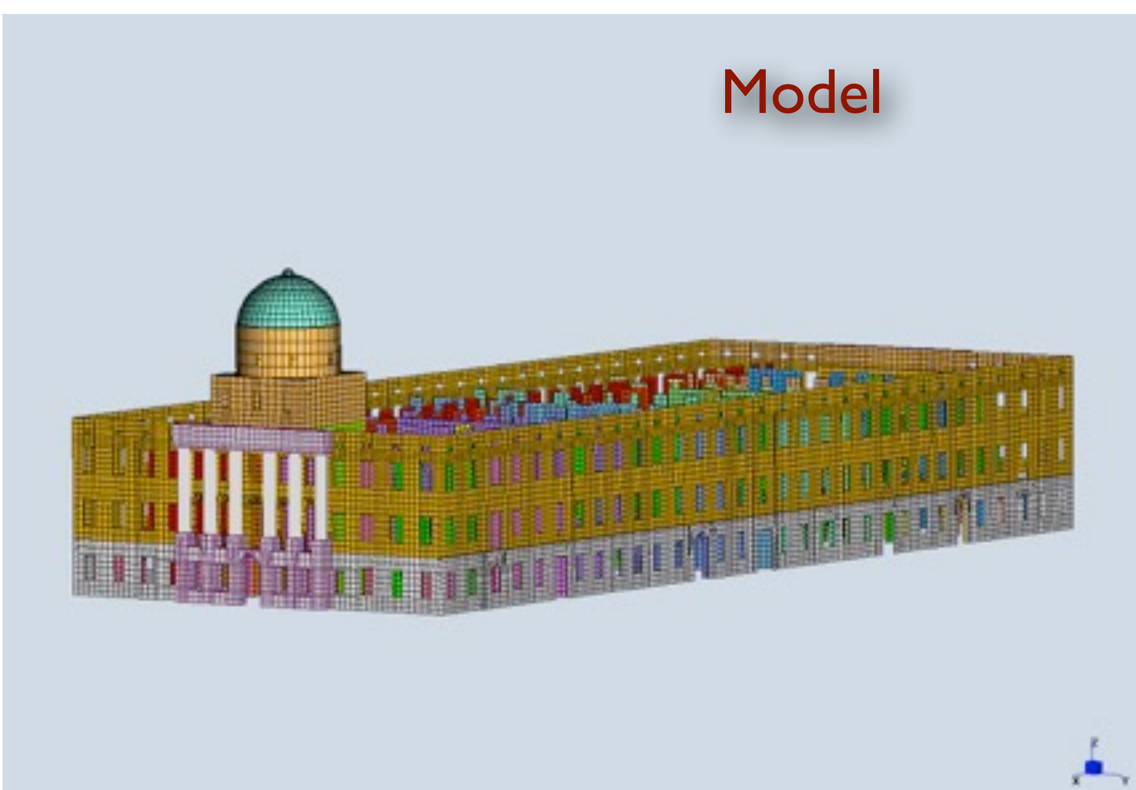
Engineering analysis - Triest case

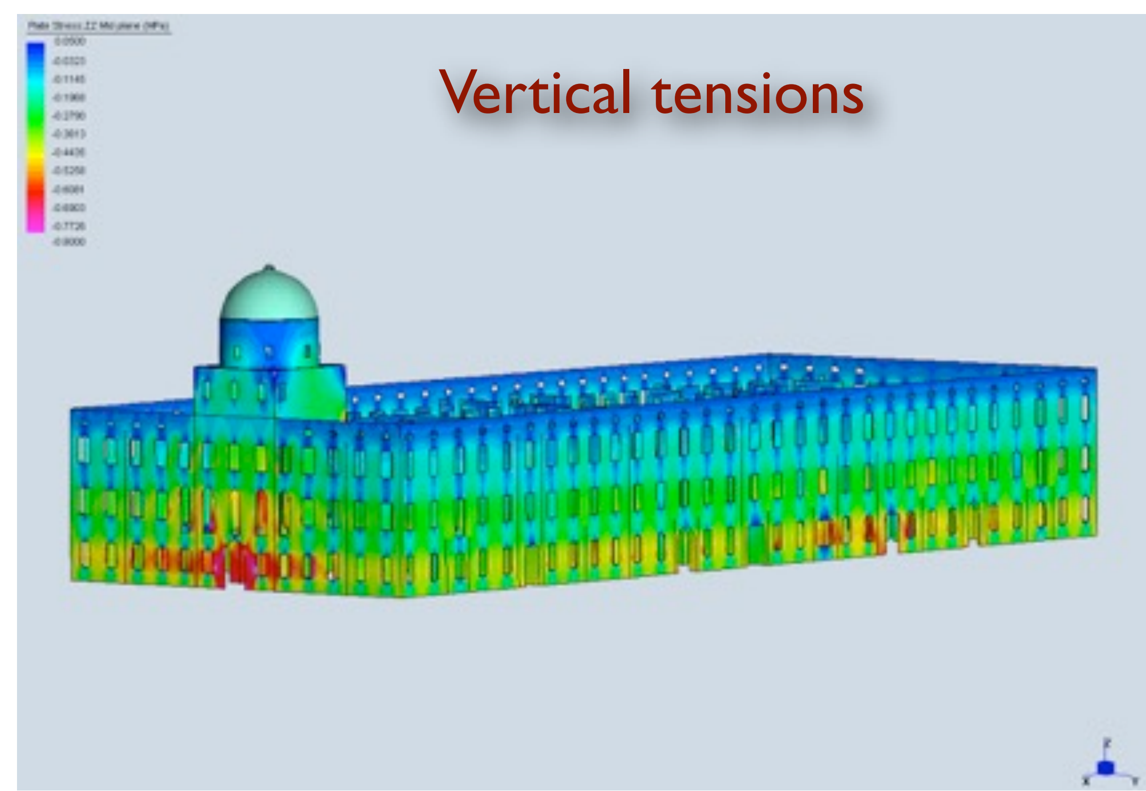
- The data set of synthetic seismograms can be fruitfully used and analysed by civil engineers for design and reinforcement actions, and therefore supply a particularly powerful and economical tool for the prevention aspects of Civil Defence.

- Non-linear dynamic analysis considering the seismic input provided by the complete synthetic accelerograms as obtained from microzoning ⇒

Evaluate the response of relevant man-made structures, in terms of displacements and stresses, with respect to a set of possible scenario earthquakes


Palazzo Carciotti (masonry)


Model


Vertical tensions