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40¹⁹⁶⁴ anniversary
2004

H4.SMR/1586-19

**"7th Workshop on Three-Dimensional Modelling
of Seismic Waves Generation and their Propagation"**

25 October - 5 November 2004

**Parametric Studies for the Definition
of the Seismic Input: A Case Study**

*Fabio ROMANELLI
Dept. Earth Sciences
Universita' degli studi di Trieste
Trieste*



7th Workshop on Three-Dimensional Modelling of Seismic
Waves Generation, Propagation and their Inversion
Miramar, 2004

Parametric studies for the definition of the seismic input: a case study

Fabio ROMANELLI

Dept. Earth Sciences
Università degli studi di Trieste
romanel@dst.units.it

VAB Project (EC)

ADVANCED METHODS FOR ASSESSING
THE SEISMIC VULNERABILITY
OF EXISTING MOTORWAY BRIDGES

ARSENAL RESEARCH, Vienna, Austria; ISMES S.P.A., Bergamo, Italy;
ICTP, Trieste, Italy; UPORTO, Porto, Portugal; CIMNE, Barcelona, Spain;
SETRA, Bagnaux, France; JRC-ISPRA, EU.

Effects on bridge seismic response of
asynchronous motion at the base of bridge piers

Source models

1) Database of focal mechanism

Longitude (°)	Latitude (°)	Focal Depth (km)	Strike (°)	Dip (°)	Rake (°)	Magnitude Ms (Mb)
16.200	48.030		180	20	90	
15.920	47.730	3	90	81	311	(4.7)
15.950	47.850	1	100	70	31	(5.4)
16.120	47.730	18	190	70	324	5.5 (4.9)
16.020	47.730	19	127	80	190	4.4

2) Parametric study on focal mechanism:

strike

dip

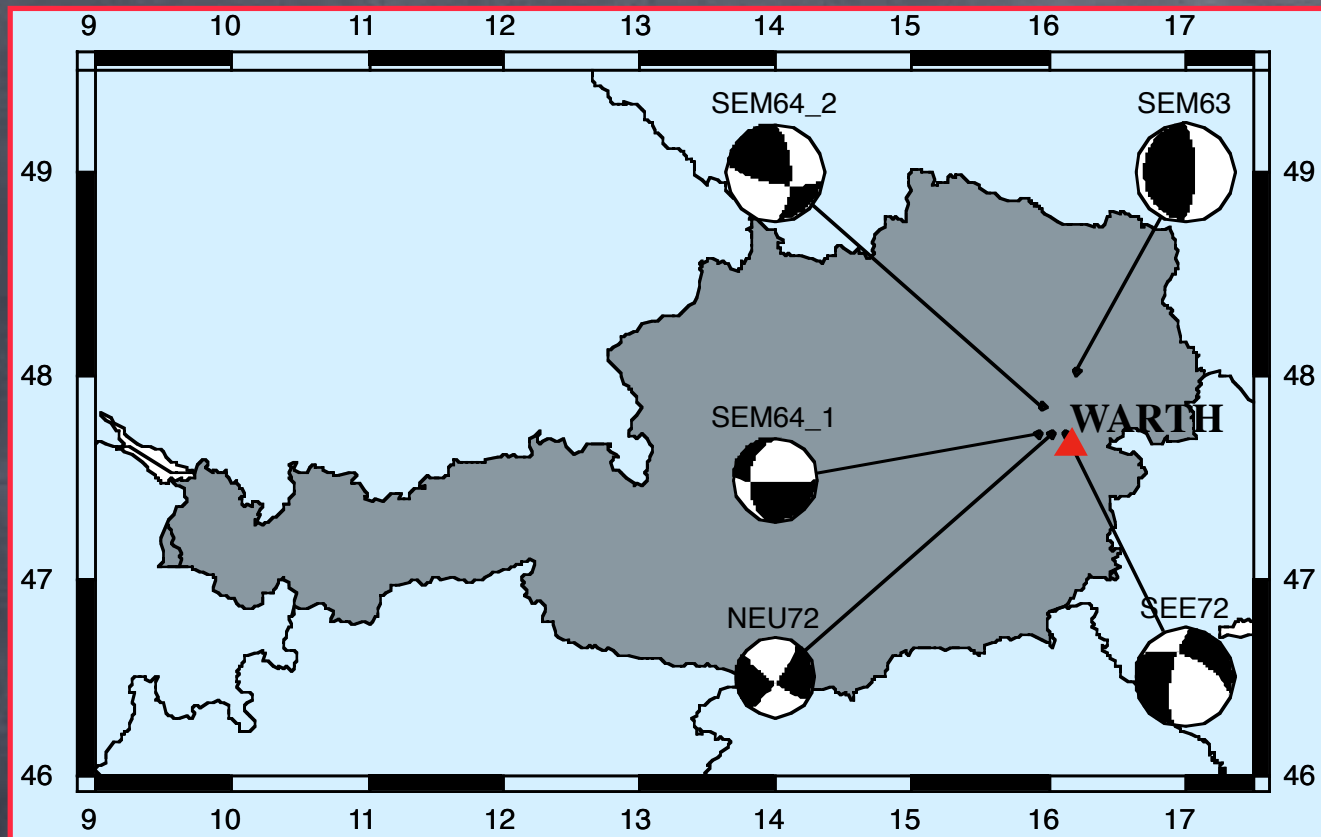
rake

depth

Maximum
Historical
Earthquake

Maximum Credible Earthquake

Maximum Design Earthquake



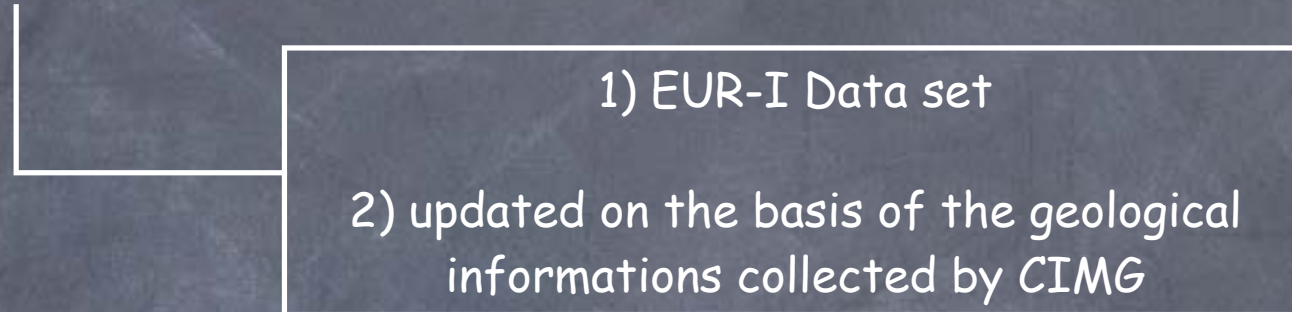
S1
Seebenstein 1972

Strike = 190°
Dip = 70°
Rake = 324°
Depth = 5 km
Mw = 5.5
Distance = 8.7 km

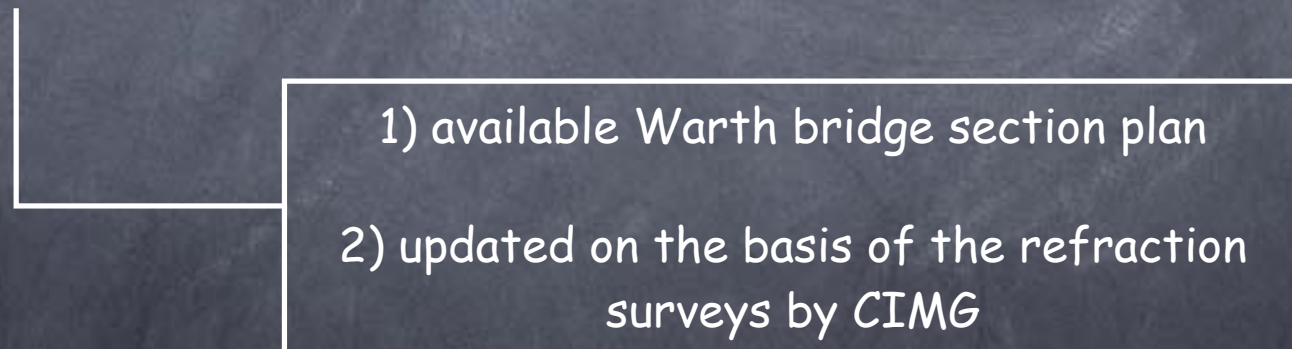
Structural models

STRUCTURAL MODELS

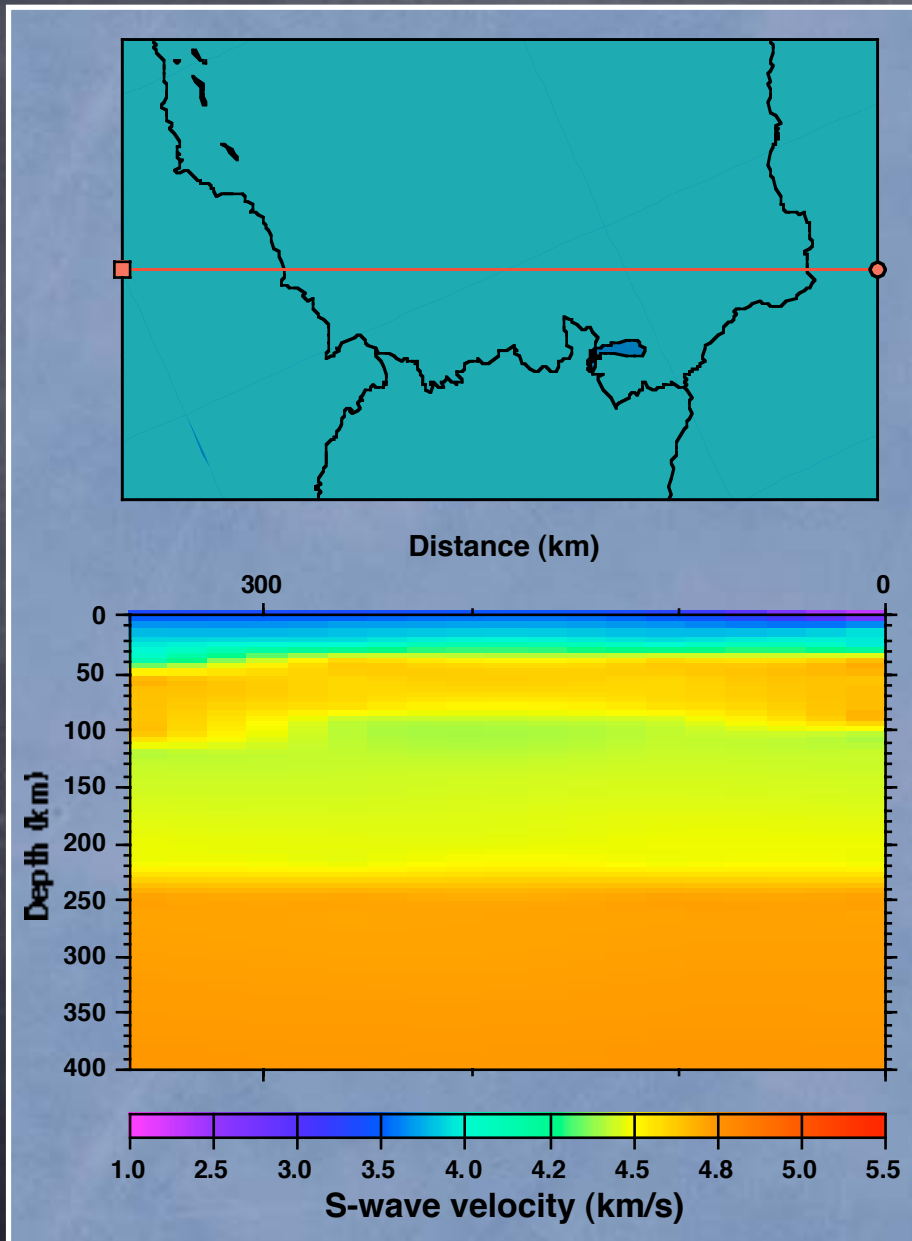
Bedrock model



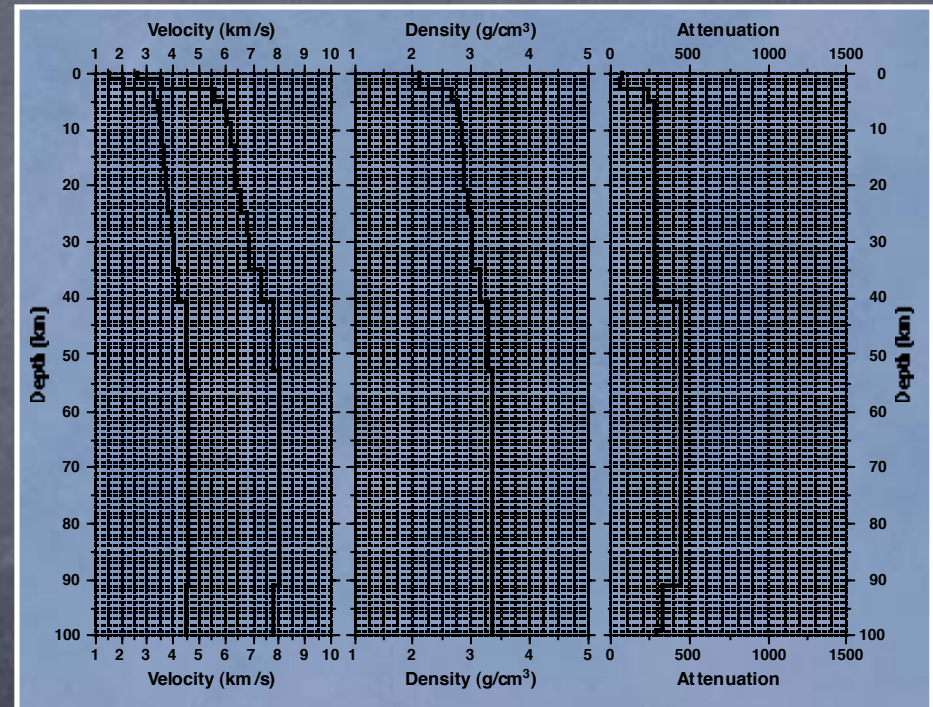
Local LHET model



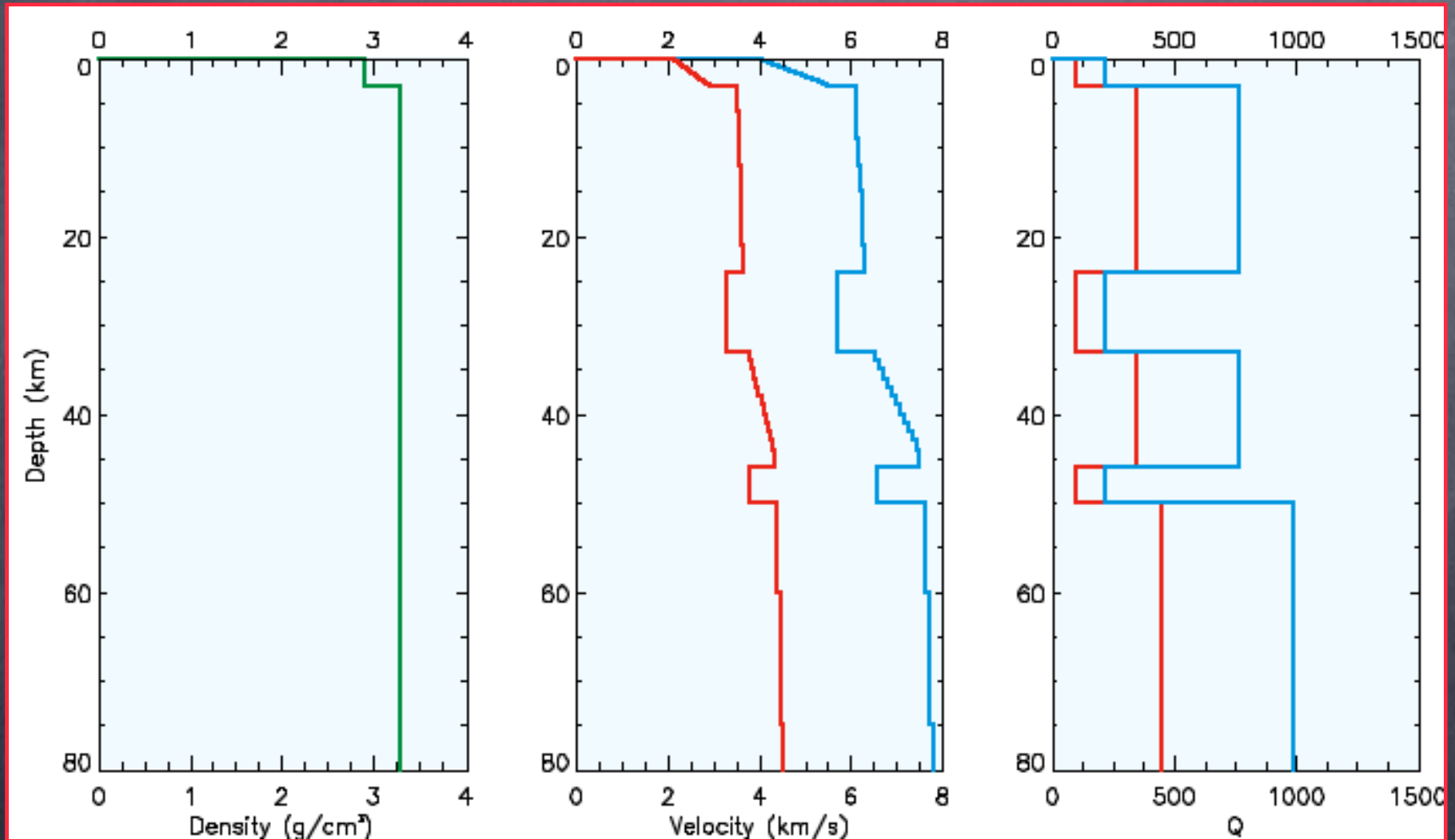
Initial regional model



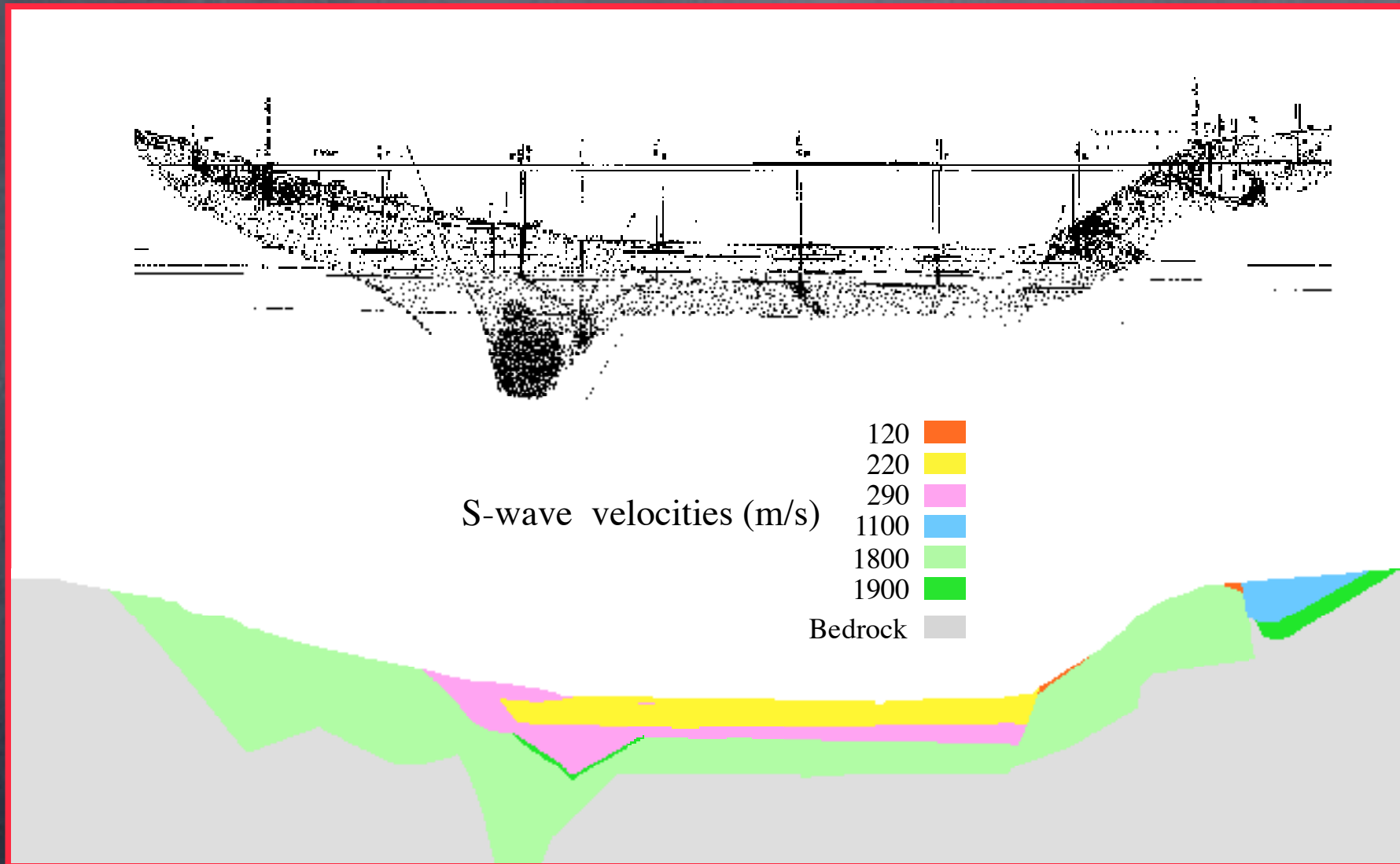
EUR I data set



Final bedrock model



Initial LHM - Warth bridge - model



COMPUTATION OF SEISMIC INPUT

PRELIMINARY COMPUTATION

INITIAL source and structural models
3 components of motion
Displacement, velocity, acceleration

FINAL COMPUTATION

FINAL source and structural models
3 components of motion
Displacement, velocity, acceleration

SEISMIC INPUT

- 1) 1D 10 Hz Parametric study
- 2) 2D 8Hz

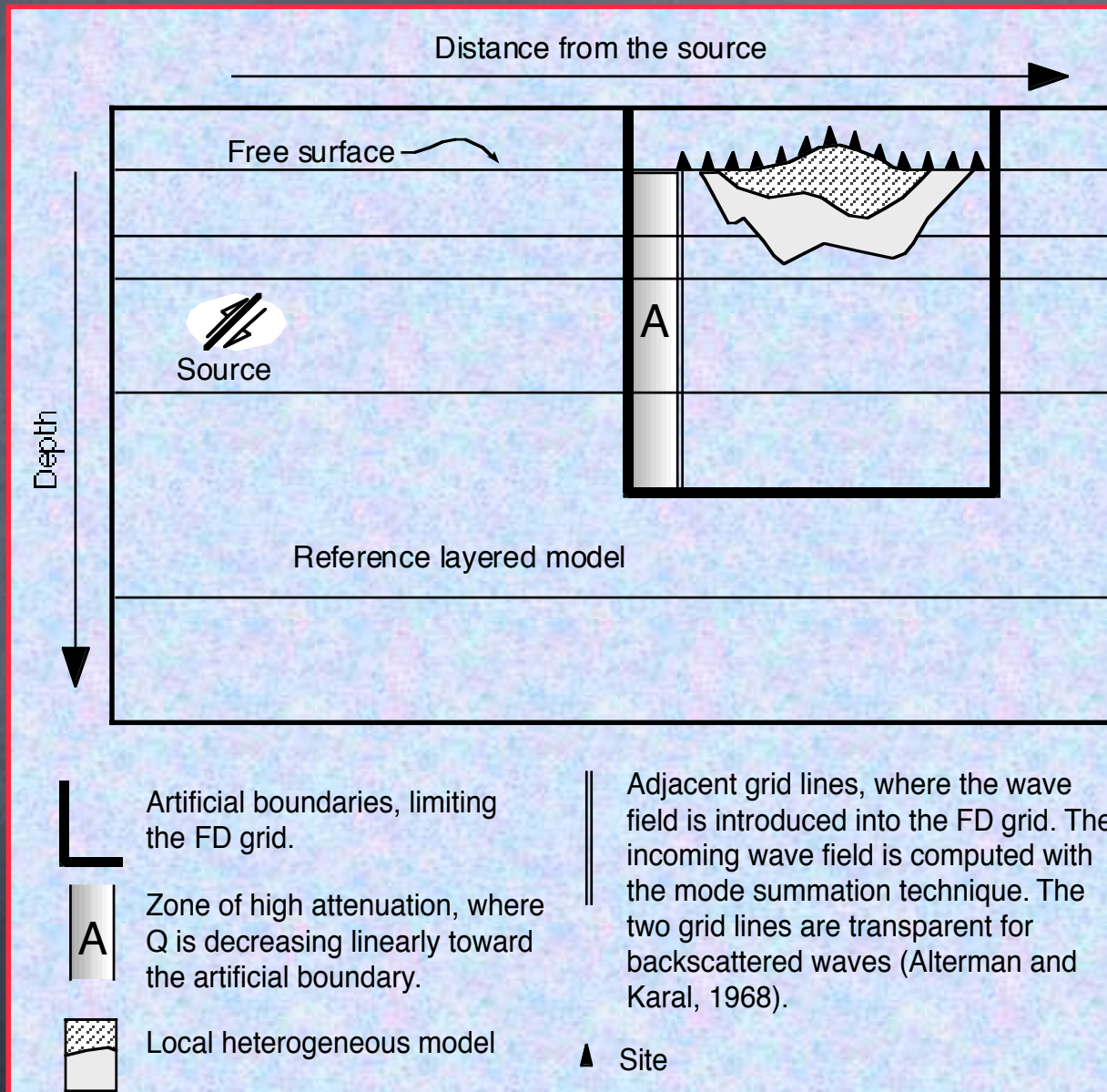
DIFFERENTIAL MOTION

- 1) time domain
- 2) spectral domain

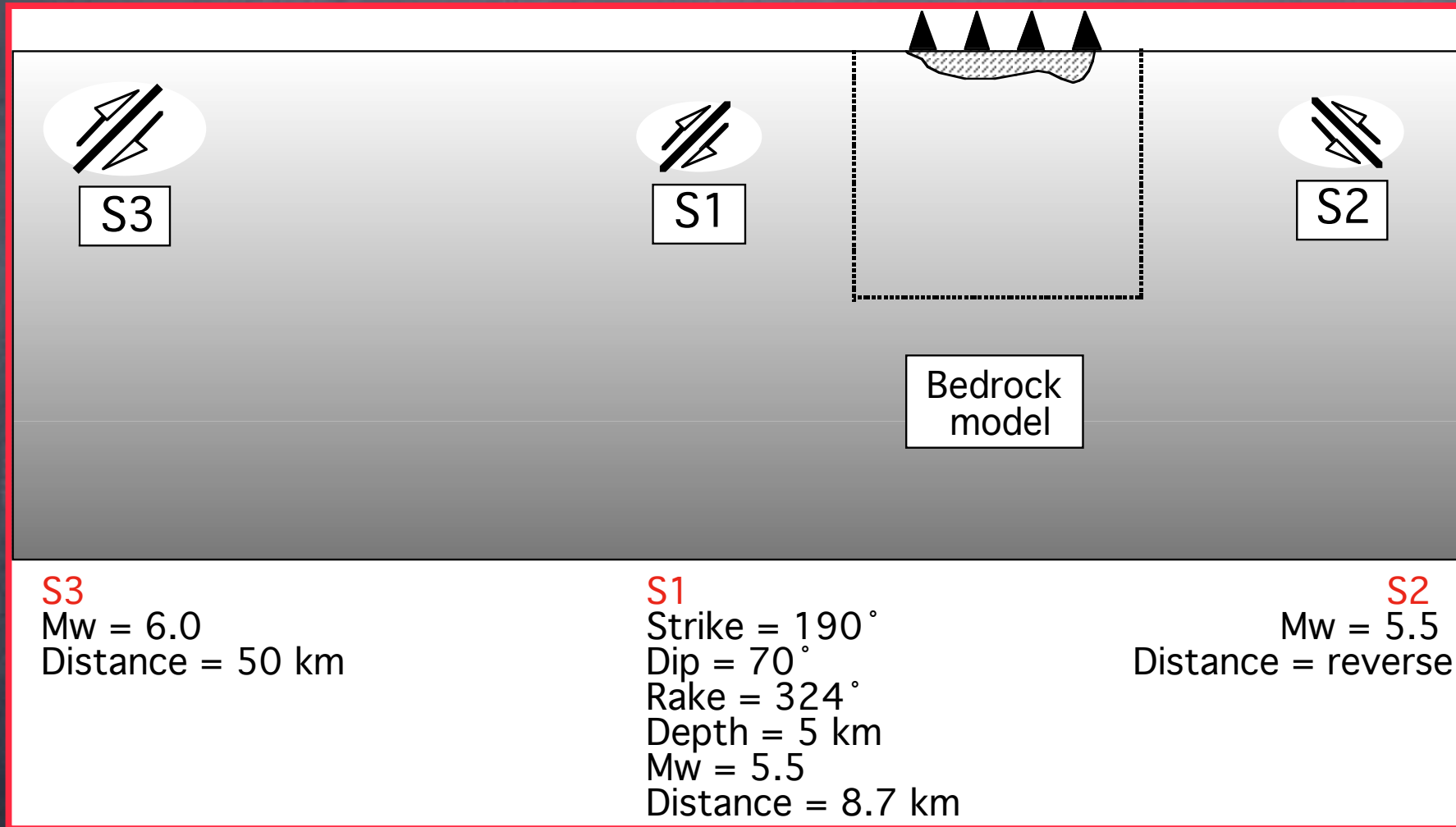
SITE RESPONSE

- 1) Fourier spectral ratios
- 2) Response spectral ratios

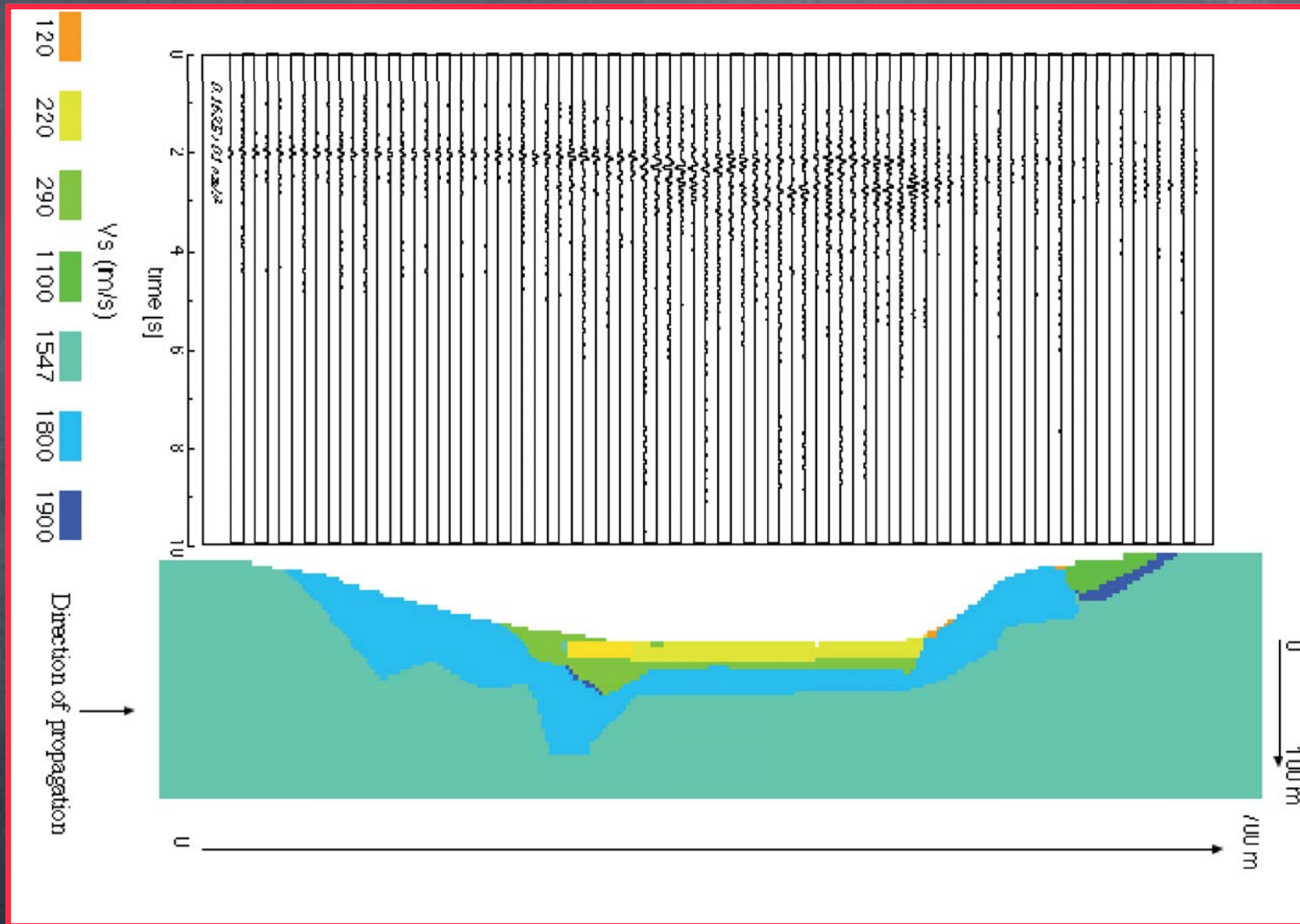
Hybrid method: MS-FD



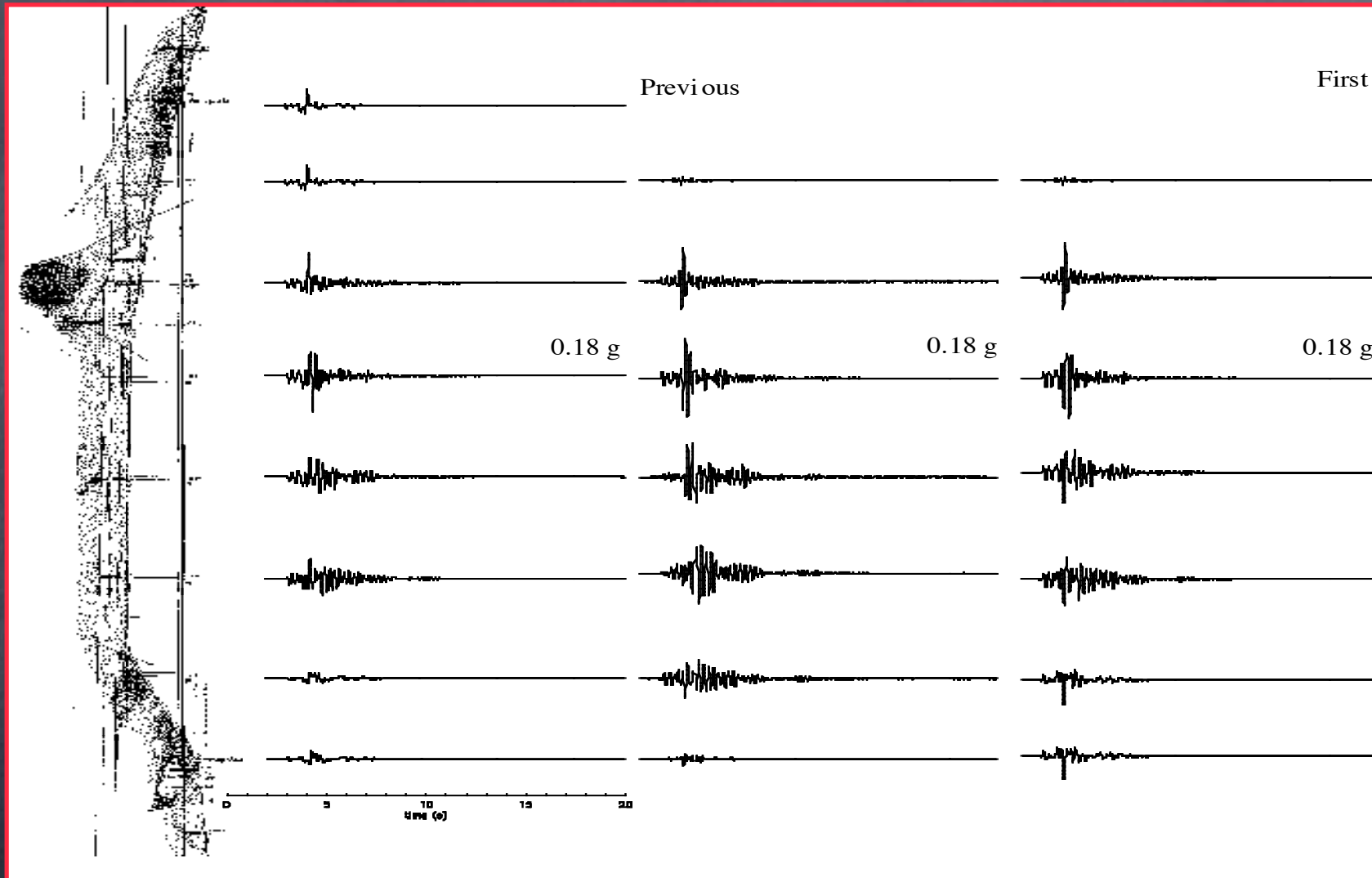
Different source-section configurations



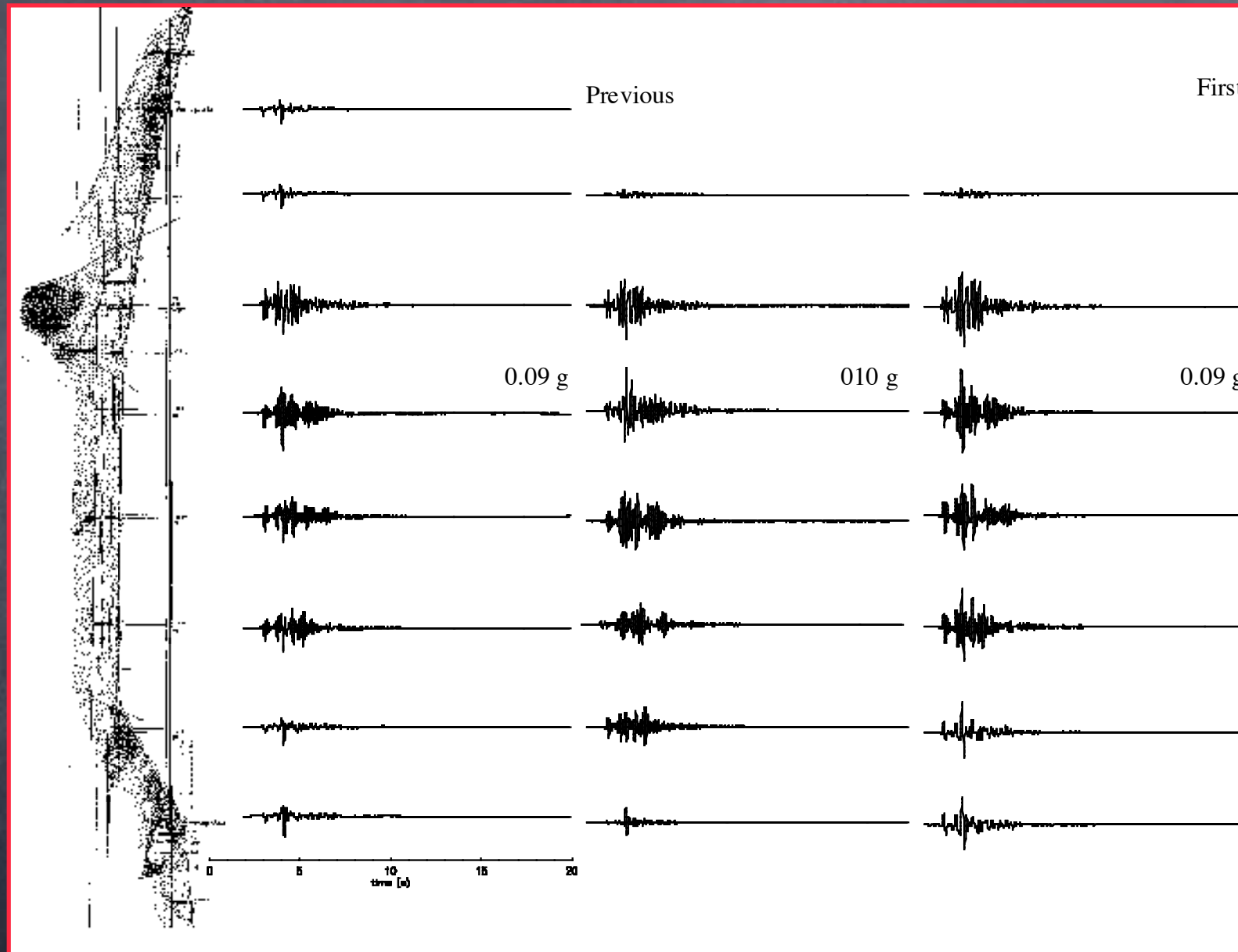
Initial synthesis - radial



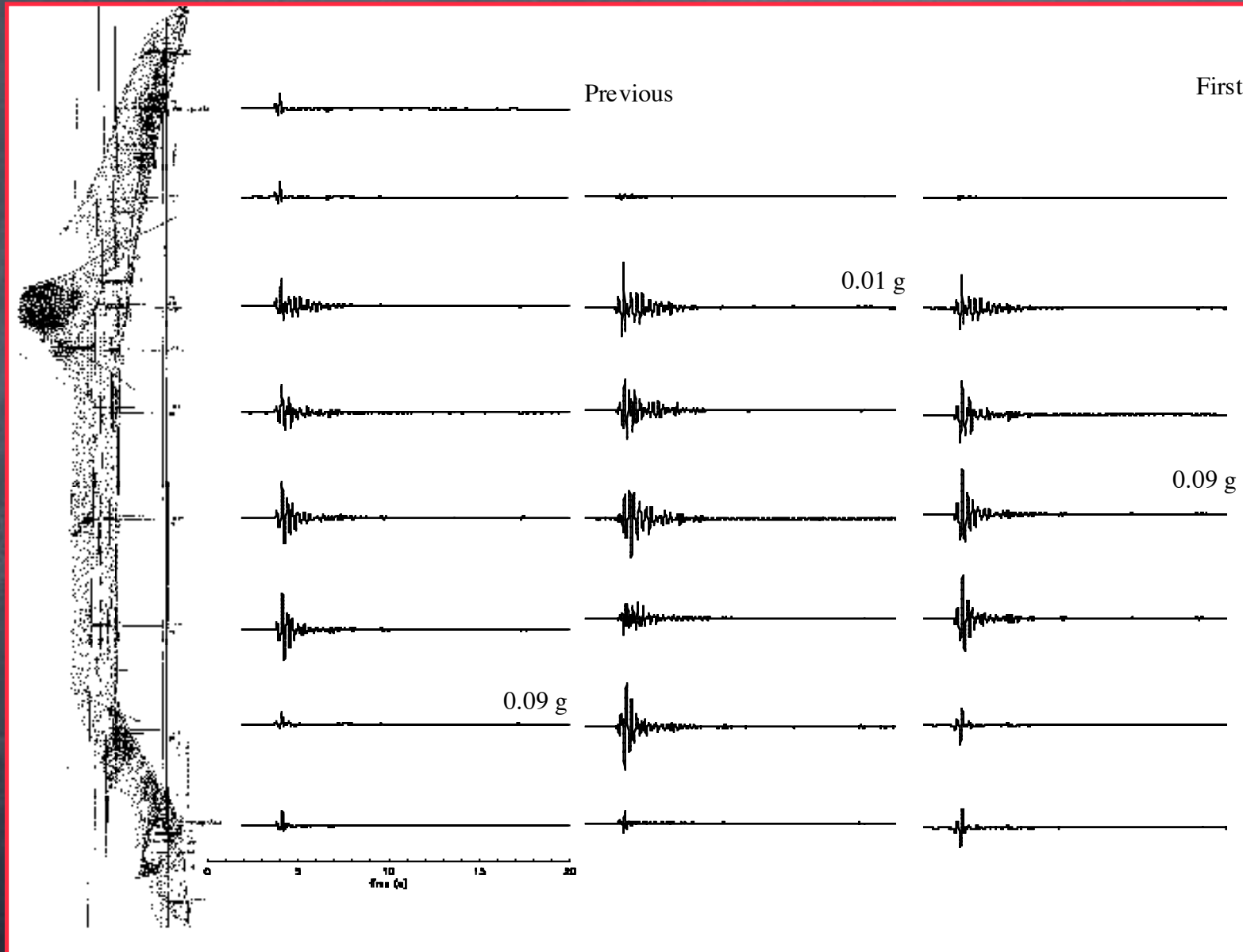
Synthetic accelerations and diffograms



Synthetic accelerations and diffograms

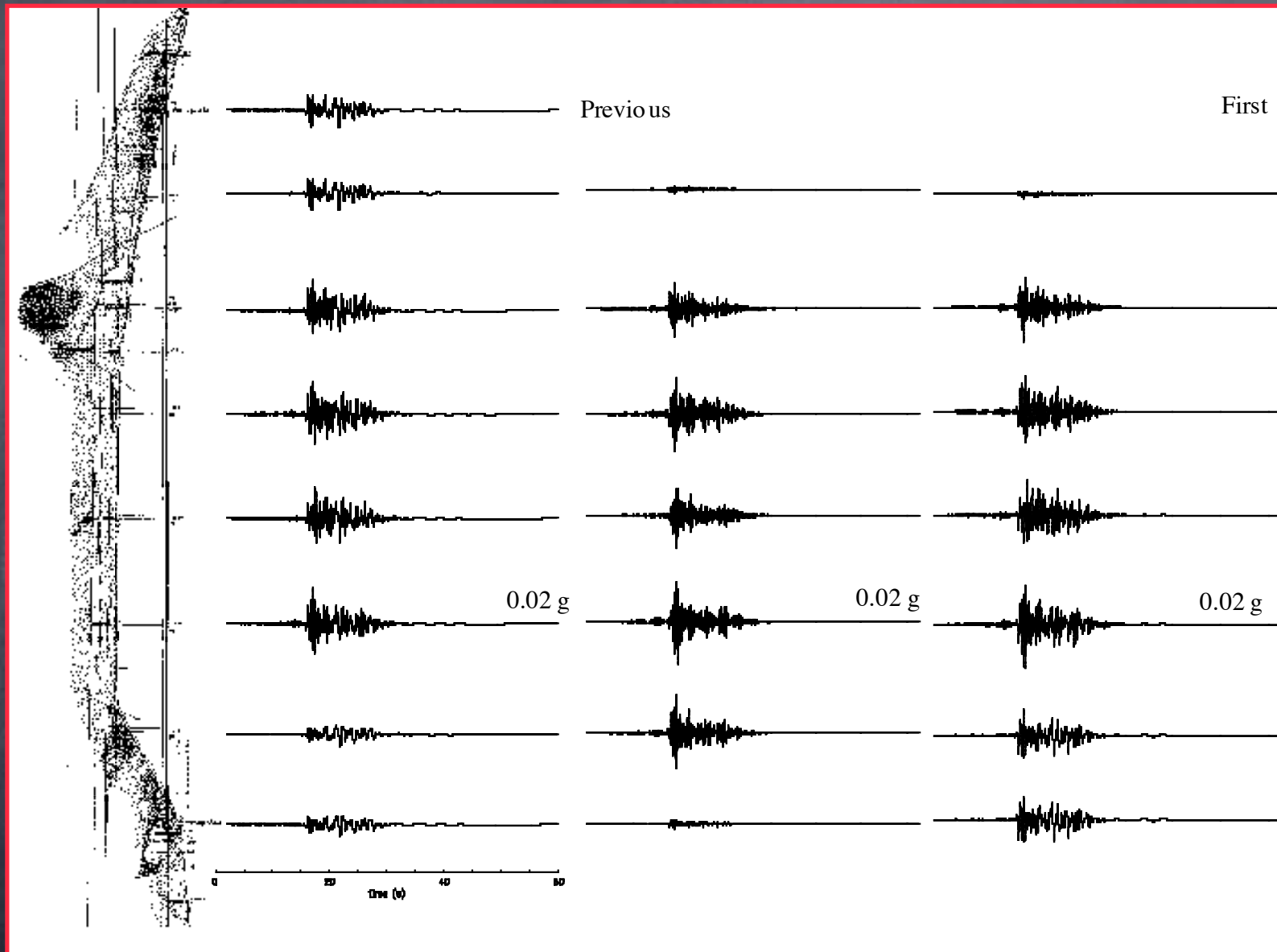


Synthetic accelerations and diffograms



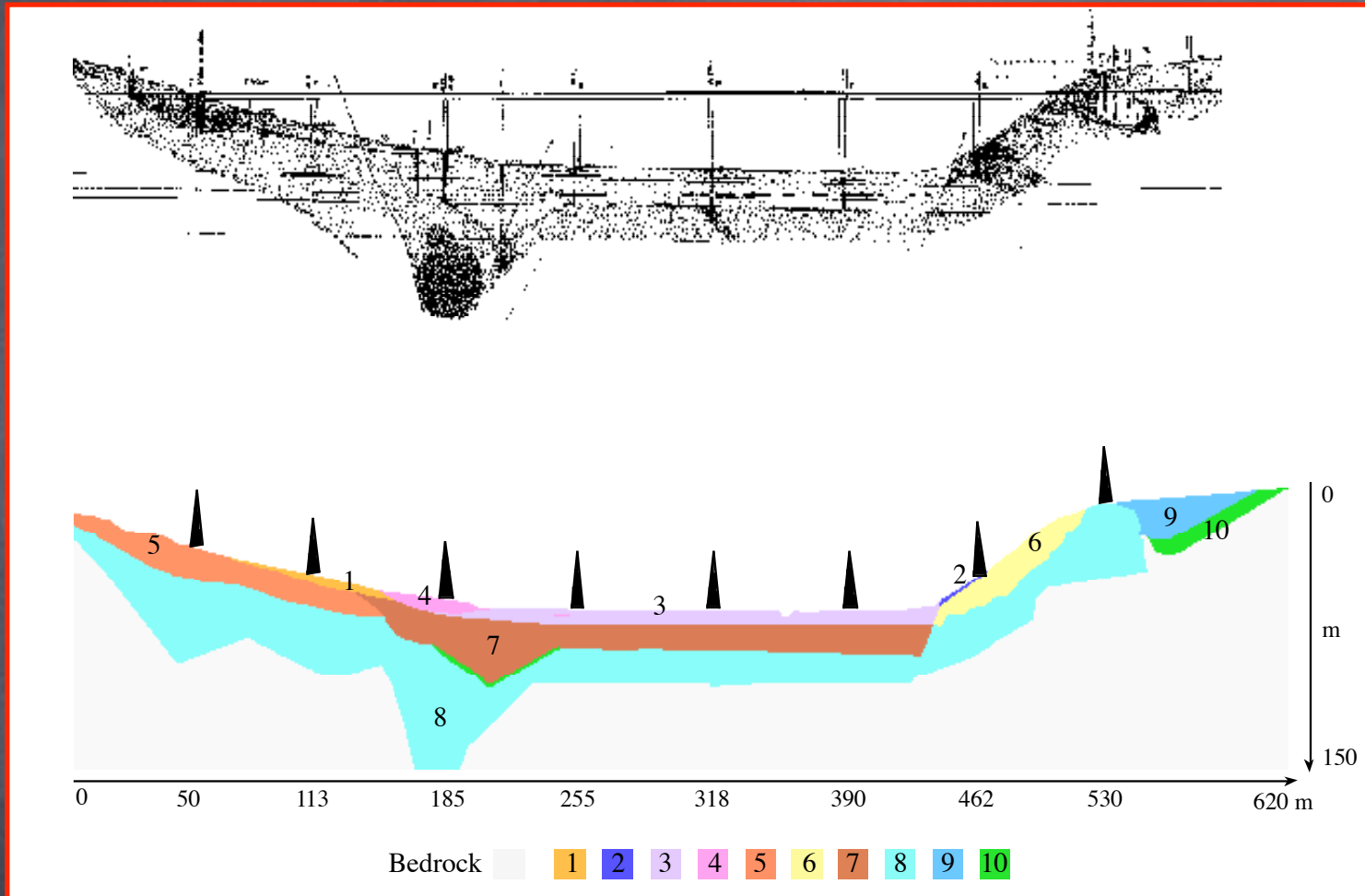
transverse

Synthetic accelerations and diffograms



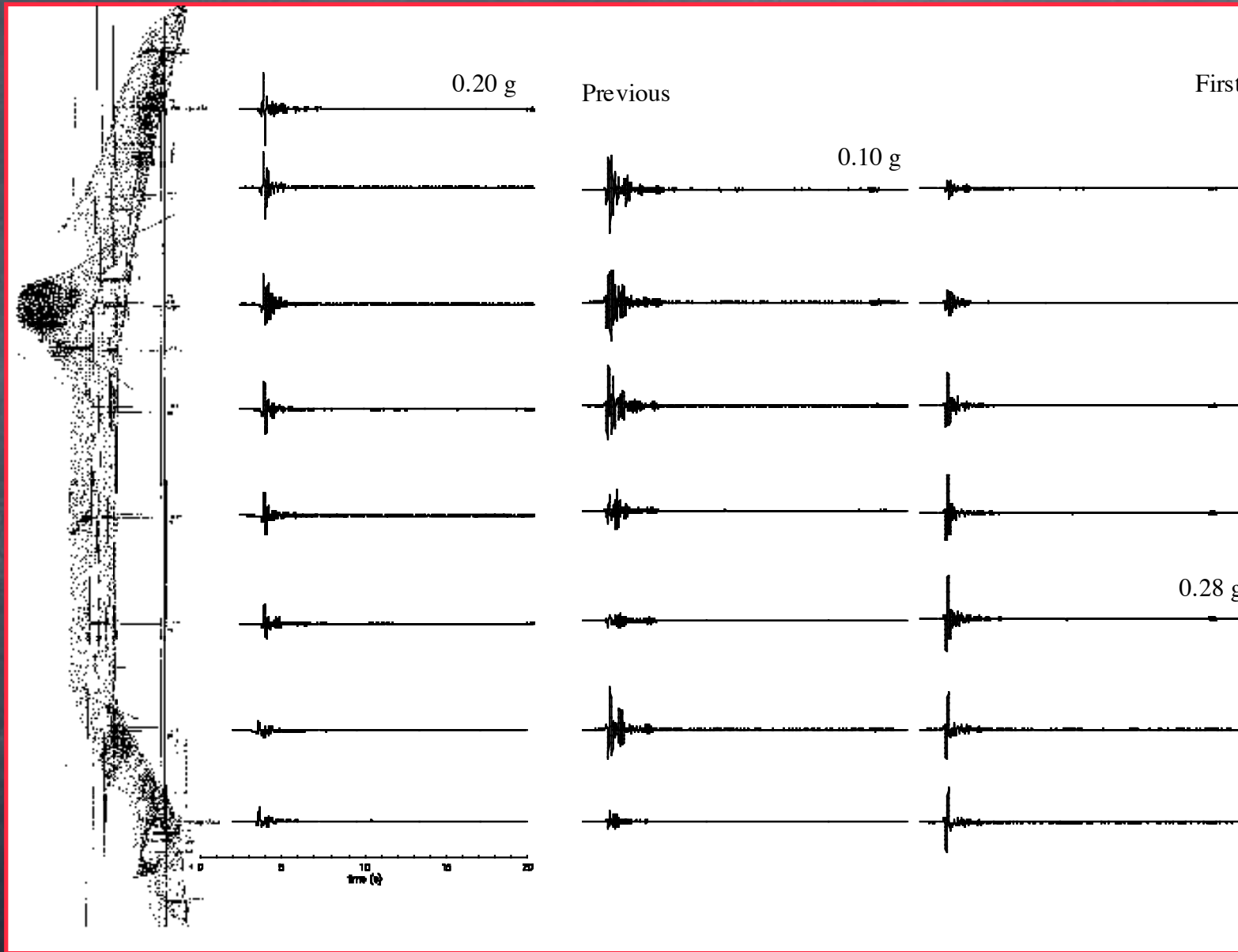
S3 - radial

LHM - Warth bridge - model



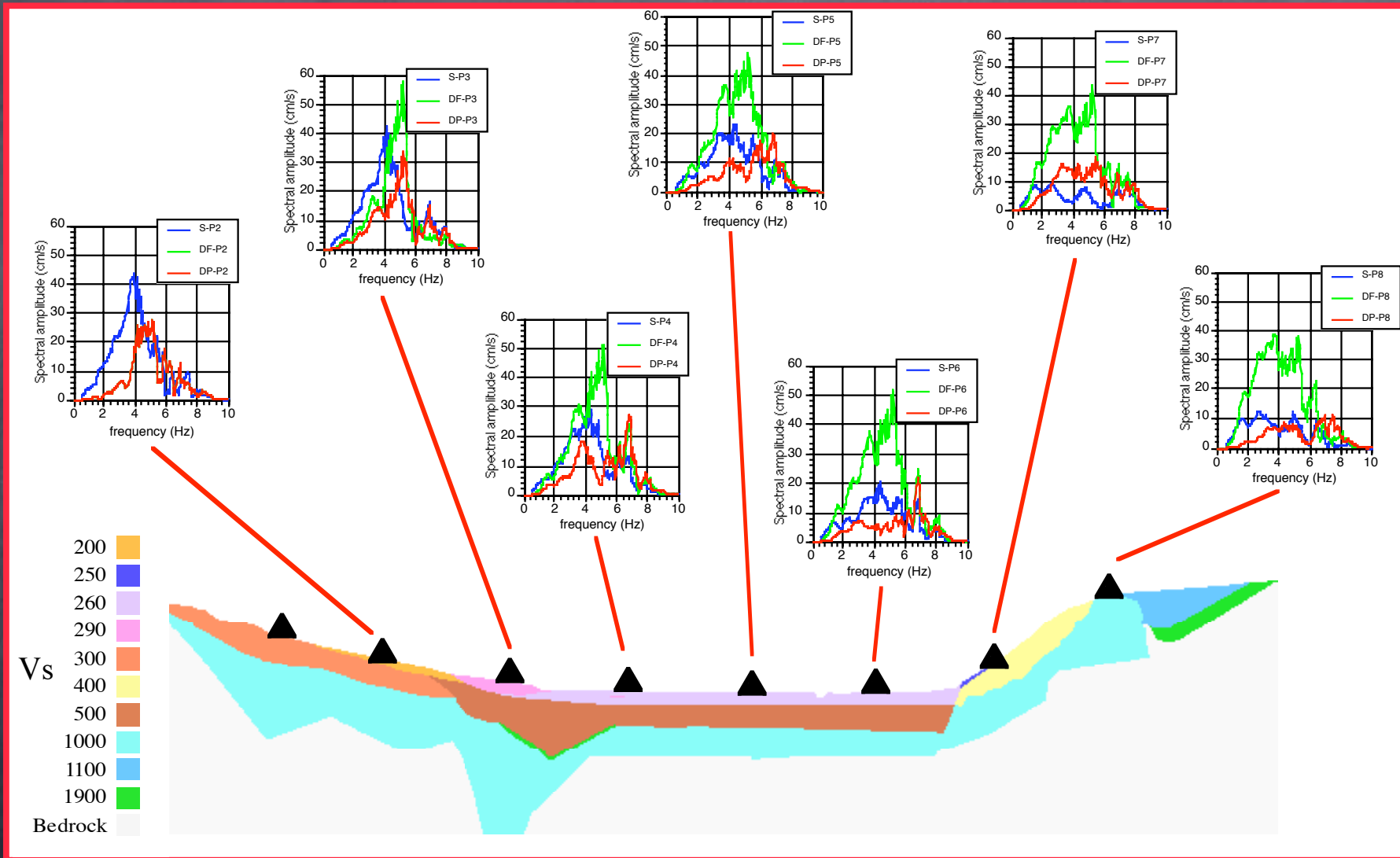
Unit	Density g/cm ³	P-wave velocity km/s	Q _P	S-wave velocity km/s	Q _S
1	1.5	0.30	40.0	0.20	15.0
2	1.7	0.49	40.0	0.25	15.0
3	2.0	0.70	50.0	0.26	20.0
4	1.8	0.70	50.0	0.29	20.0
5	2.3	0.80	50.0	0.30	20.0
6	2.3	0.80	50.0	0.40	20.0
7	1.8	1.70	50.0	0.50	20.0
8	2.3	2.10	150.0	1.00	60.0
9	2.3	3.00	150.0	1.90	60.0
10	2.2	1.80	100.0	1.10	40.0

Synthetic accelerations and diffograms



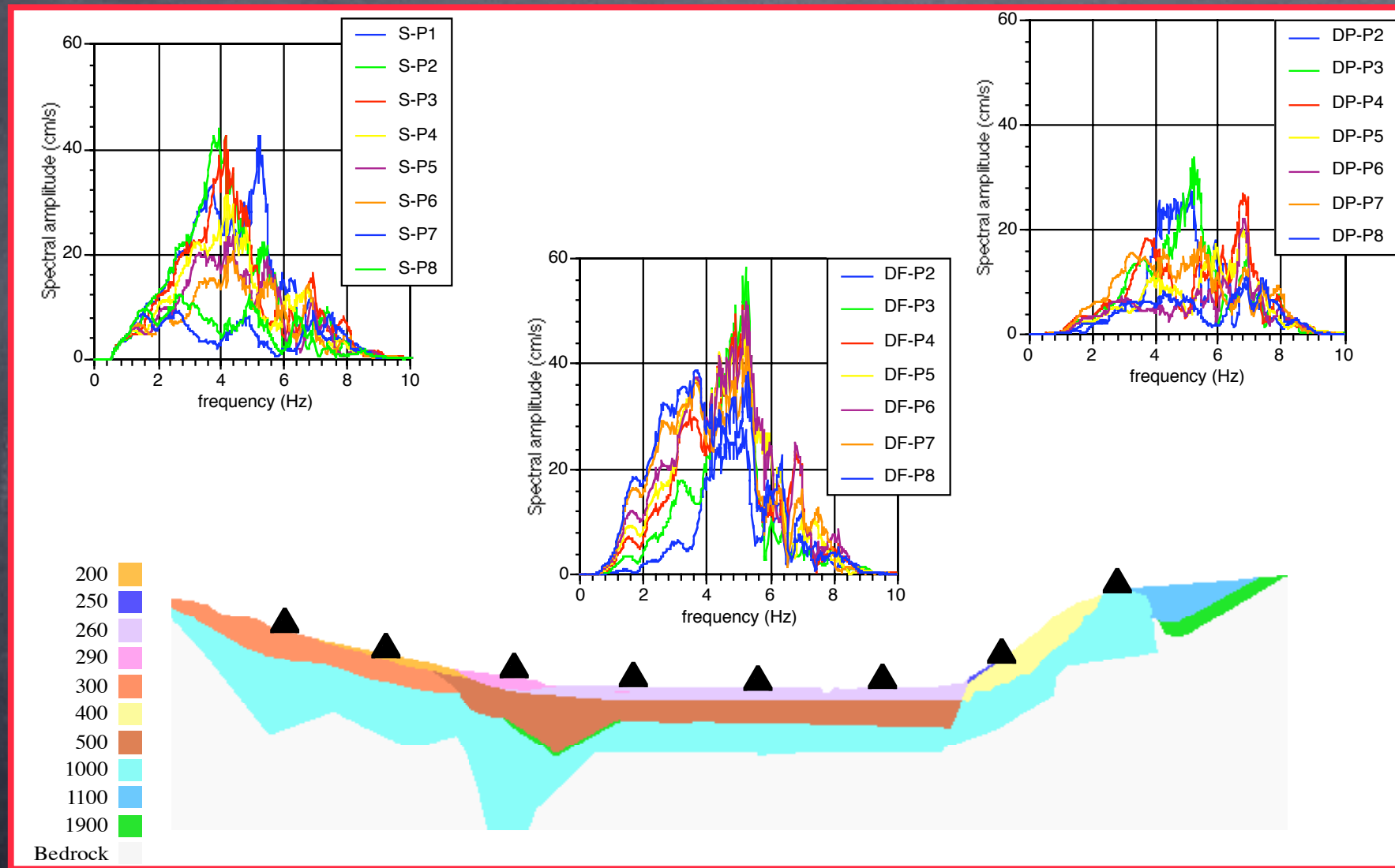
Synthetic accelerations and diffograms

Frequency domain - Amplitude spectra



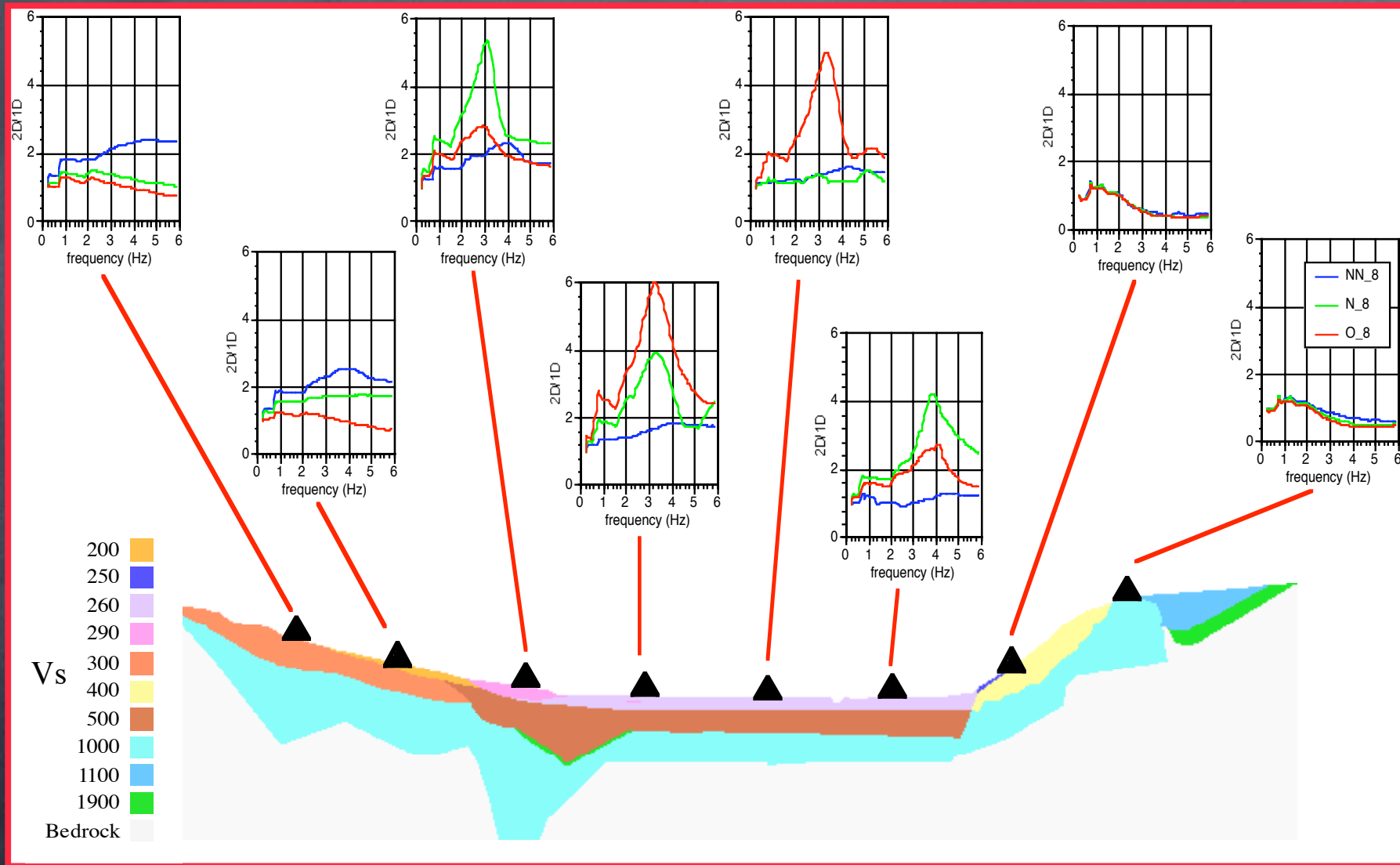
Synthetic accelerations and diffograms

Frequency domain - Amplitude spectra



Synthetic accelerations

RS domain - Amplification



PARAMETRIC STUDY - Fp towards MCE

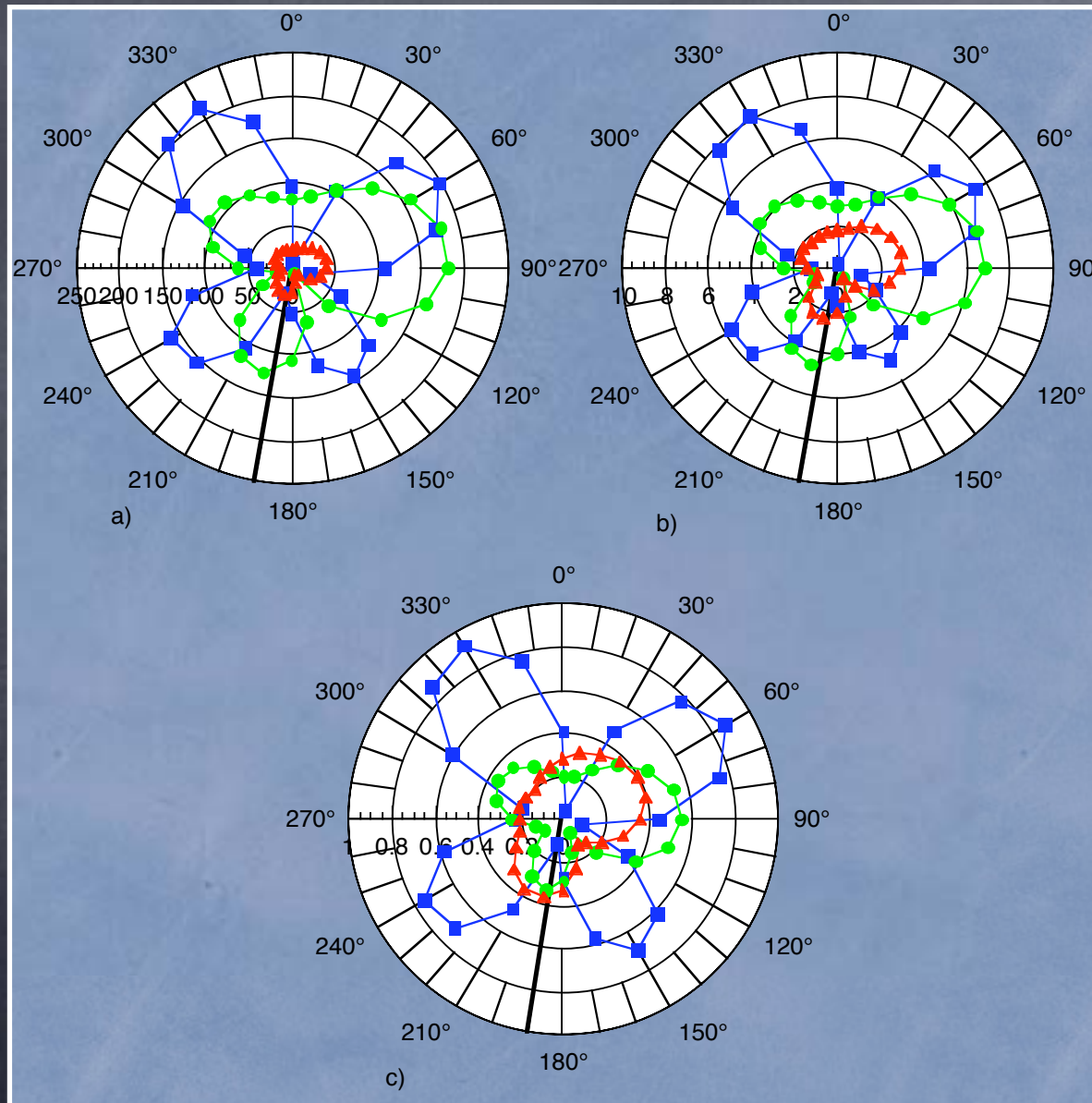
All the focal mechanism parameters of the original source model have been varied in order to find the combination producing the maximum amplitude of the various ground motion components.

Longitude (°)	Latitude (°)	Focal Depth (km)	Strike (°)	Dip (°)	Rake (°)	Magnitude Ms (Mb)
16.120	47.730	18	190	70	324	5.5 (4.9)

- 1) Strike angle (Depth=5km)
- 2) Rake angle
- 3) Strike-Rake angles variation (Dip=45°)
- 4) Strike-Rake angles variation (Dip=70°)
- 5) Strike-Rake angles variation (Dip=90°)
- 6) Depth-Distance variation
(Strike=60°, Dip=70°, Rake=0, 90°)

The computations of synthetic seismograms (displacements, velocities and accelerations for the radial, transverse and vertical components) have been carried out with cut-off frequency 10 Hz.

Parametric study 1: strike

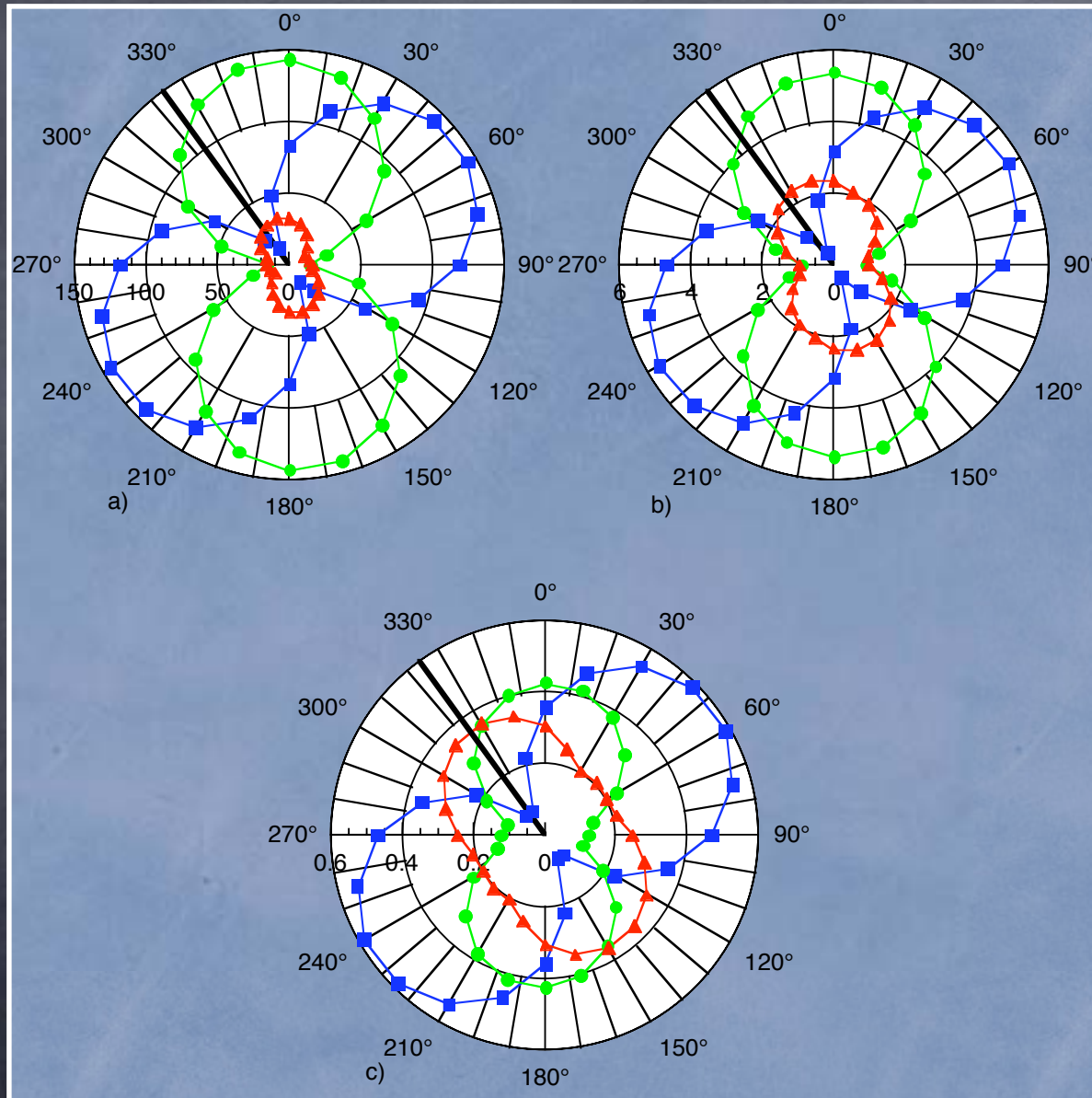


Polar plot of the maximum amplitude of the ground motion:
a) acceleration (cm/s^2)
b) velocity (cm/s)
c) displacement (cm)

versus the strike angle

for the three components:
transverse (squares);
radial (circles);
vertical (triangles)

Parametric study 1: rake

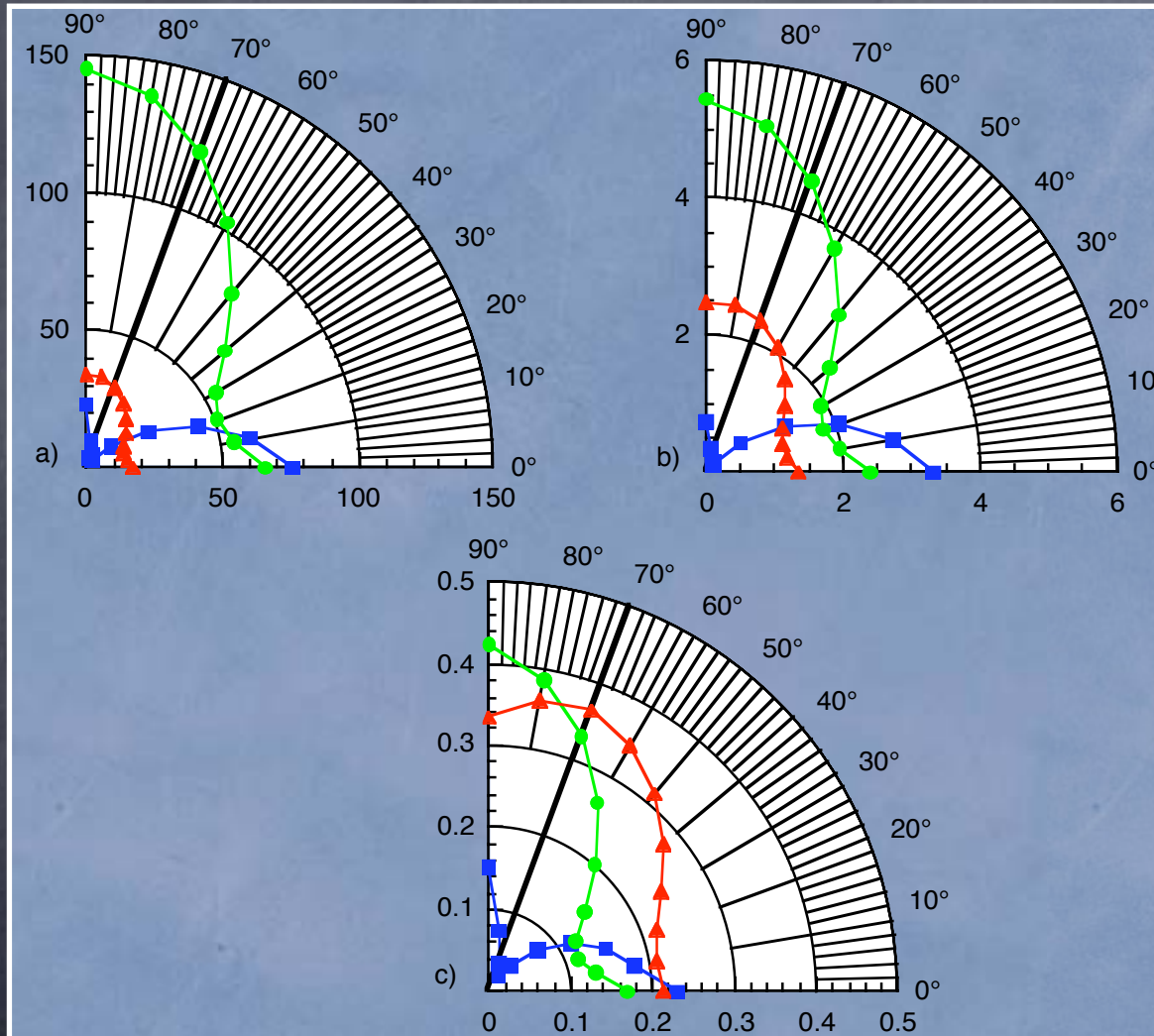


Polar plot of the maximum amplitude of the ground motion:
a) acceleration (cm/s^2)
b) velocity (cm/s)
c) displacement (cm)

versus the rake angle

for the three components:
transverse (squares);
radial (circles);
vertical (triangles)

Parametric study 1: dip

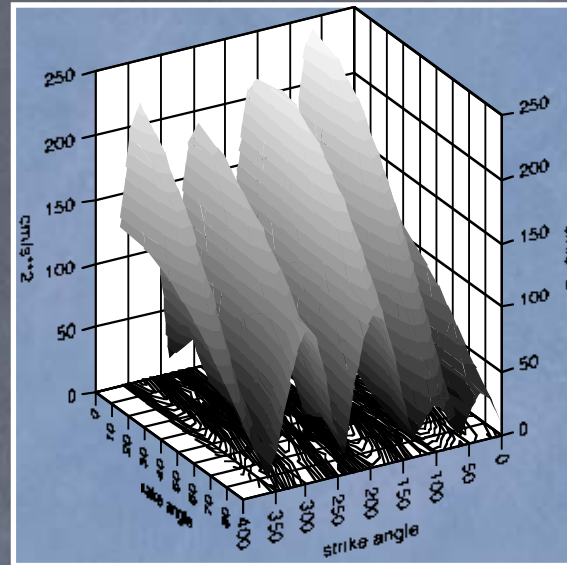
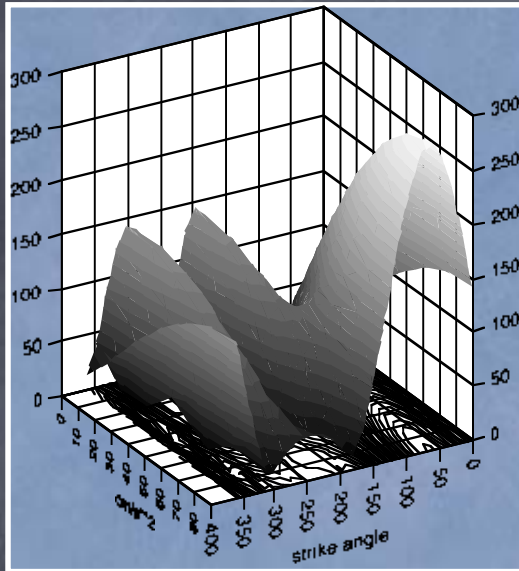


Polar plot of the maximum amplitude of the ground motion:
a) acceleration (cm/s²)
b) velocity (cm/s);
c) displacement (cm)

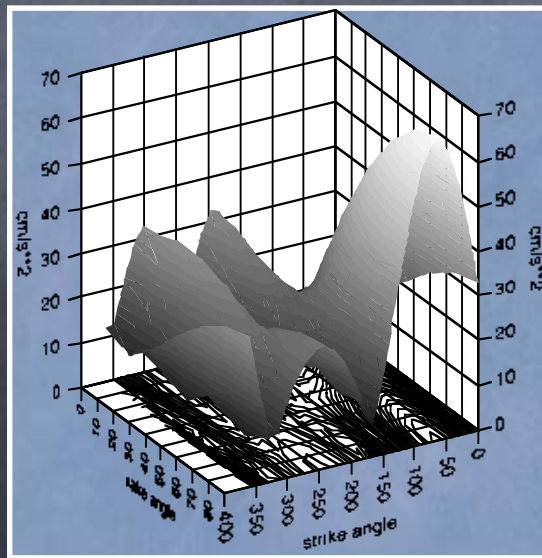
versus the dip angle

for the three components:
transverse (squares);
radial (circles);
vertical (triangles)

Parametric study 1: s&r



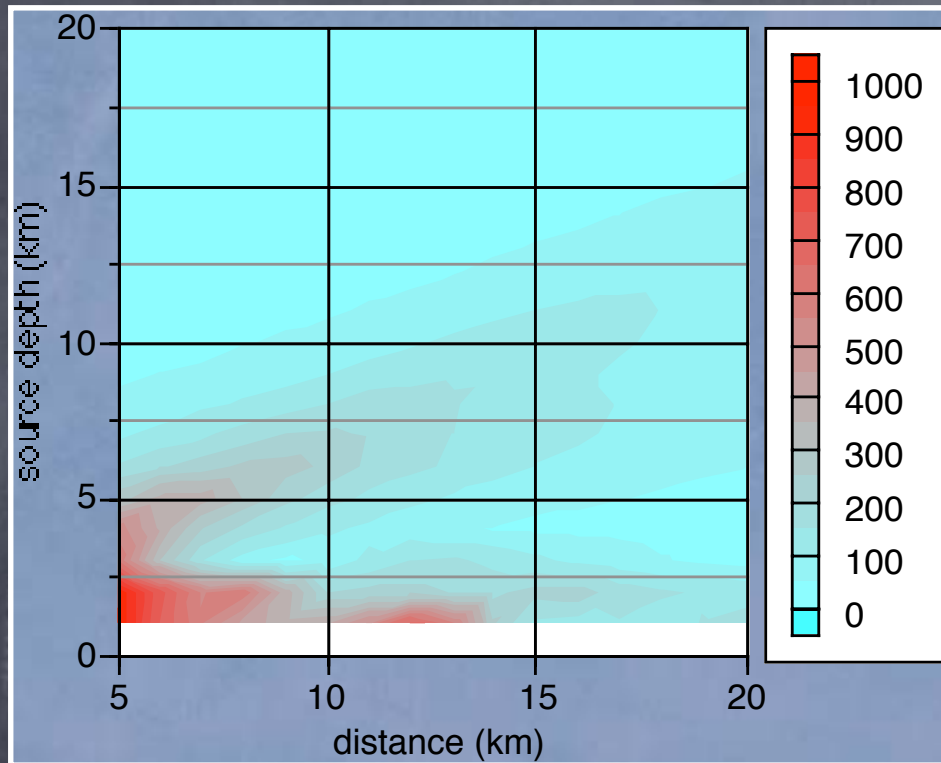
Polar plot of the maximum amplitude of the acceleration ground motion - dip angle is 70°



versus the strike and rake angle

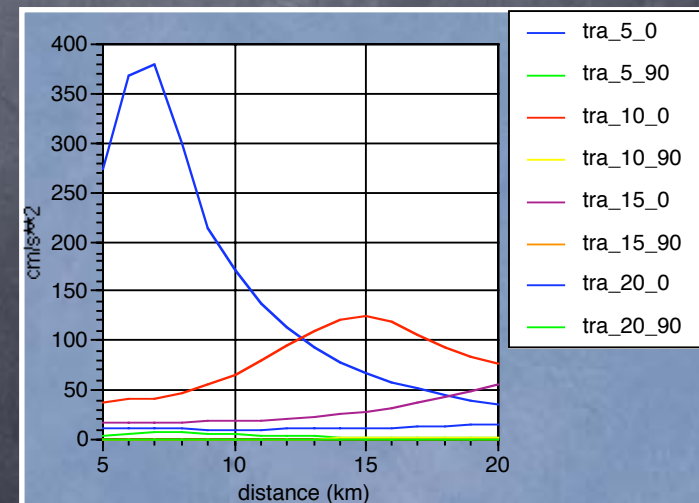
for the three components of motion

Parametric study 1: h&d

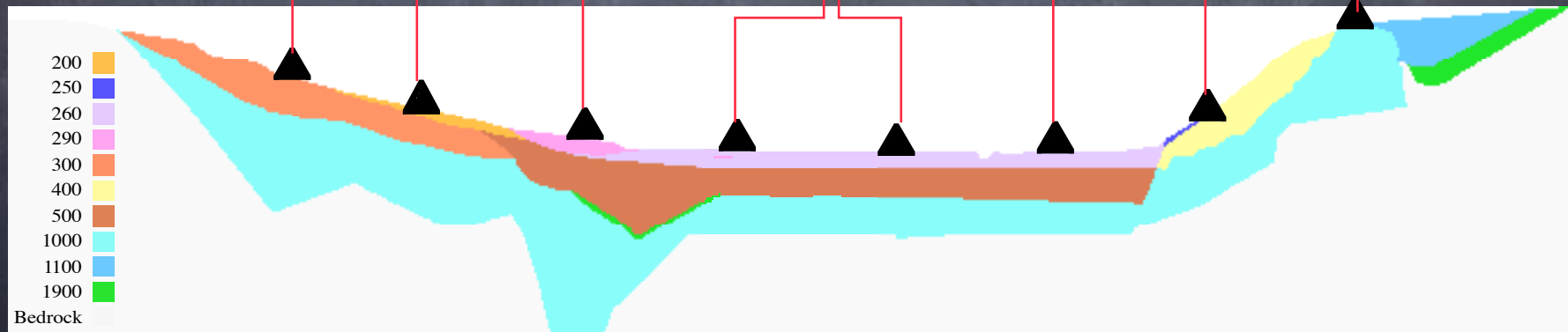
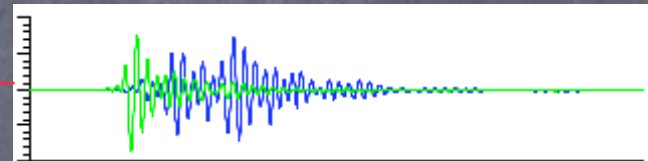
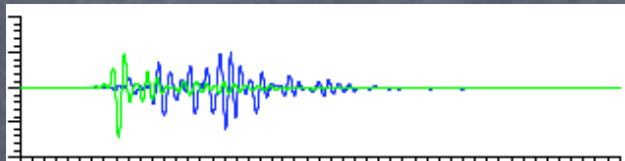
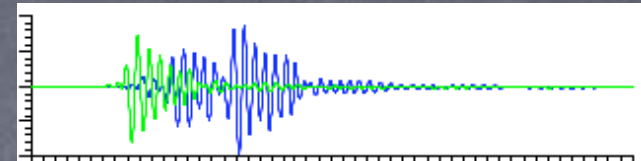
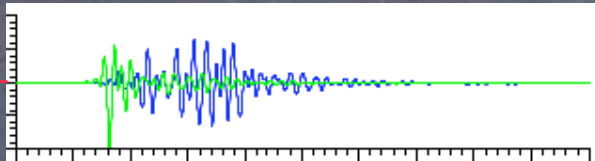
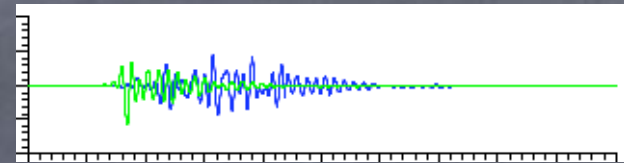
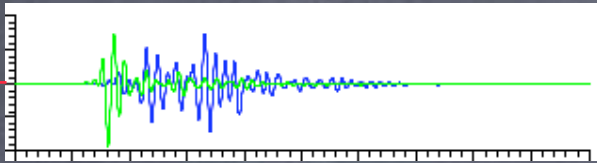
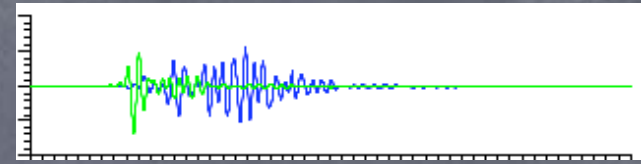
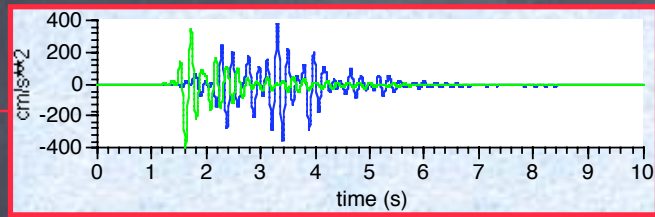


Plot of the maximum amplitude
of the acceleration ground
motion - cm/s^2 -
versus the
epicentral distance
and
source depth

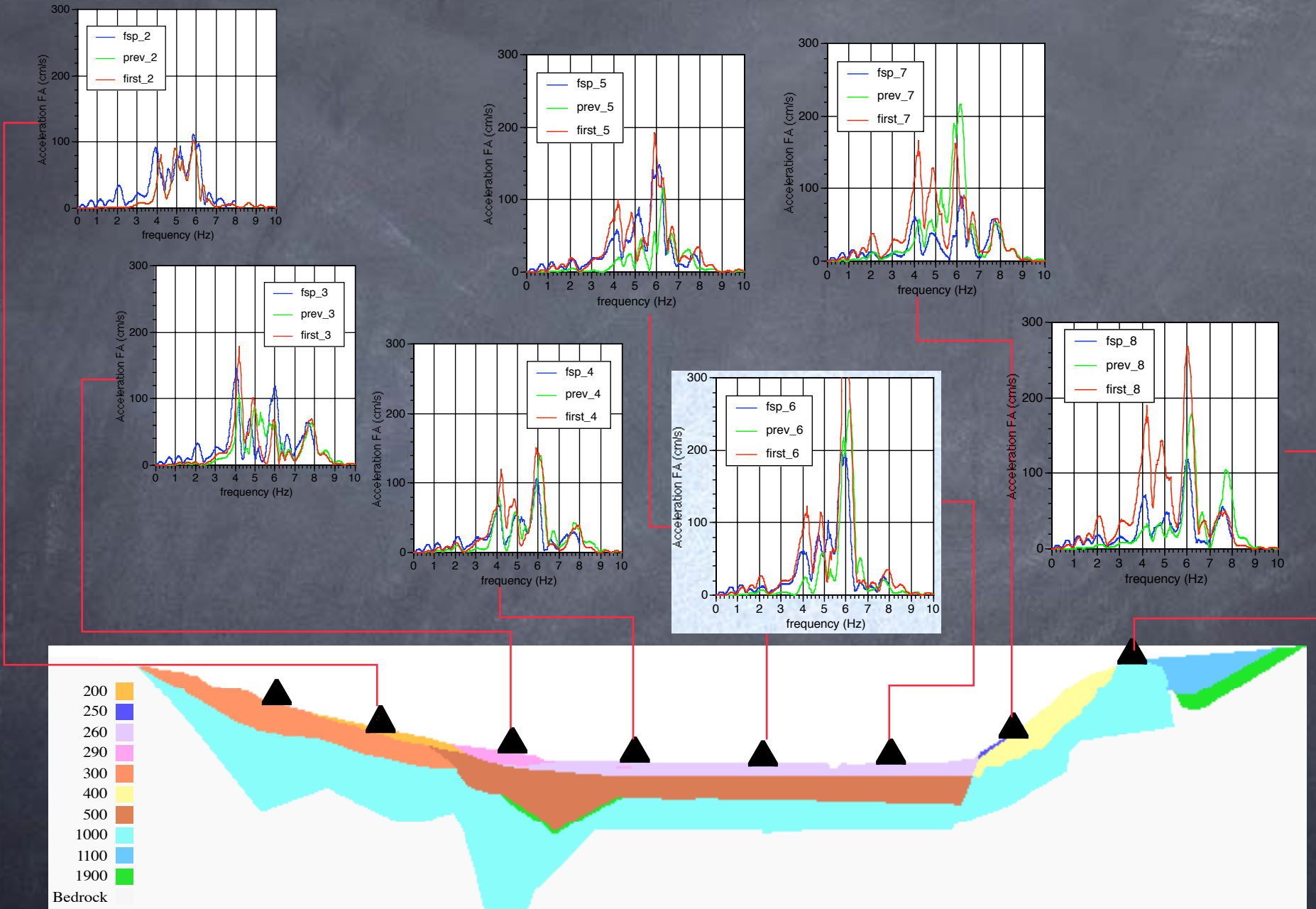
transverse component
dip angle = 70°



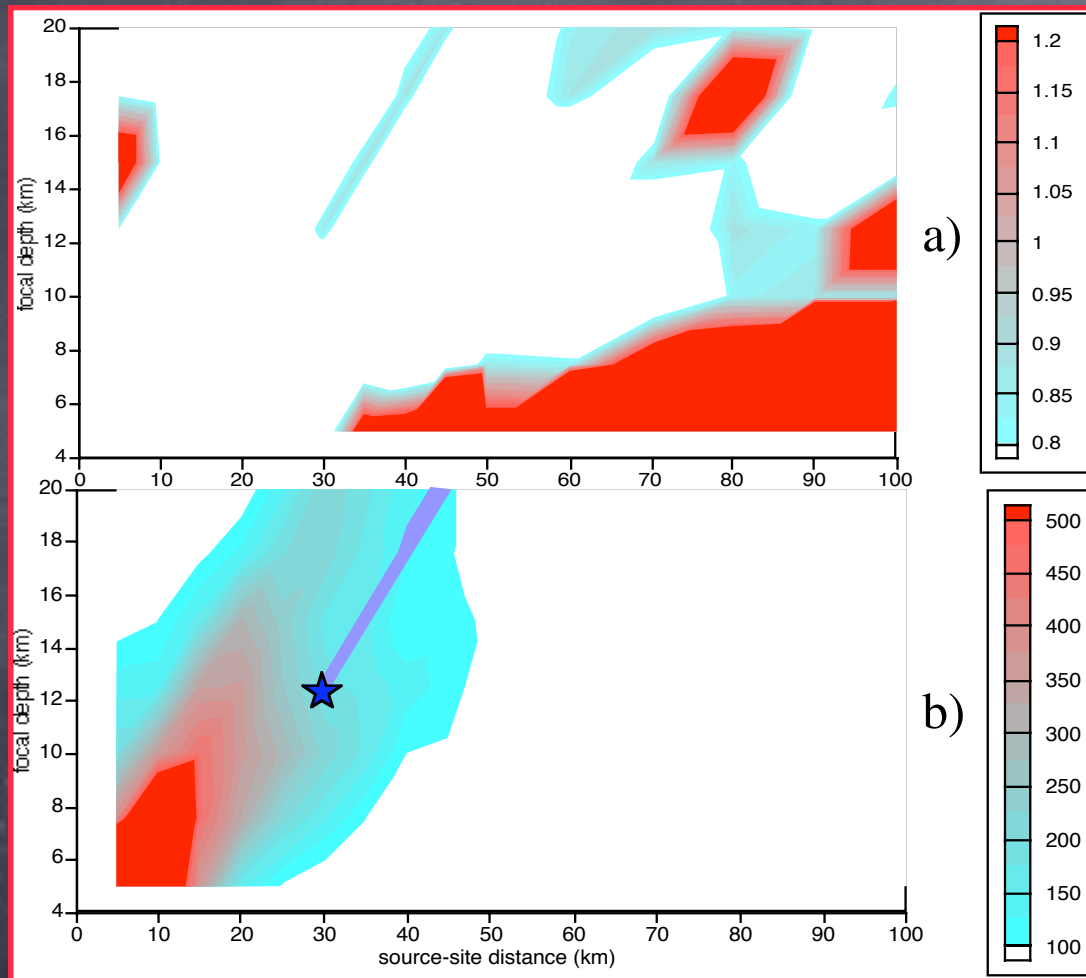
Transverse accelerograms $M=5.5$



Tranverse acceleration spectra



PARAMETRIC STUDY 2 - F_p towards 1 Hz

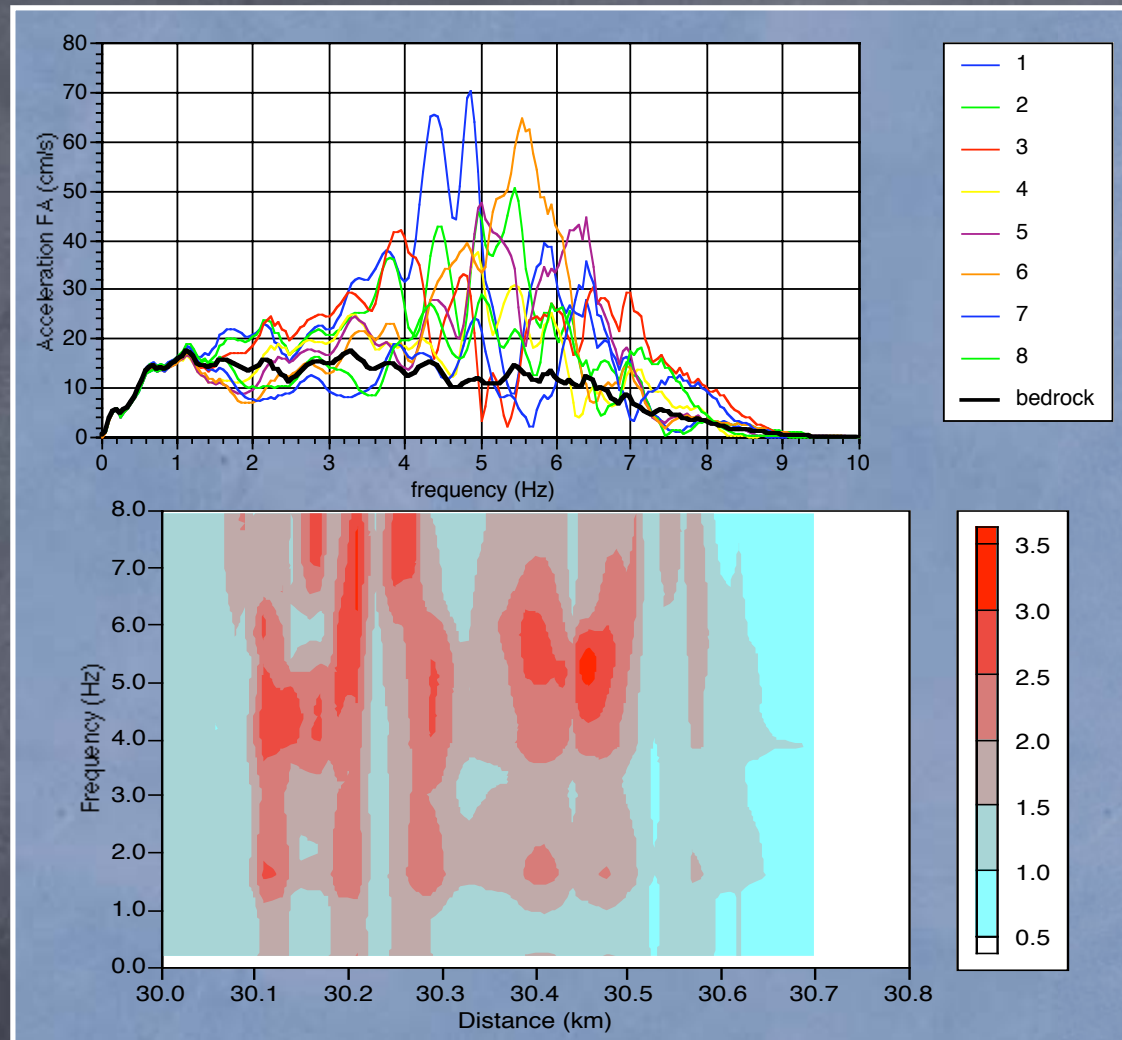


Another parametric study has been performed in order to find a seismic source-Warth site configuration providing a set of signals whose seismic energy is concentrated around 1 Hz, frequency that corresponds approximately to that of the fundamental transverse mode of oscillation of the bridge.

The results show that, in order to reach a relevant value of PGA (e.g. greater than 0.1g) in the desired period range (i.e. 0.8-1.2 s), an alternative and suitable configuration is a source

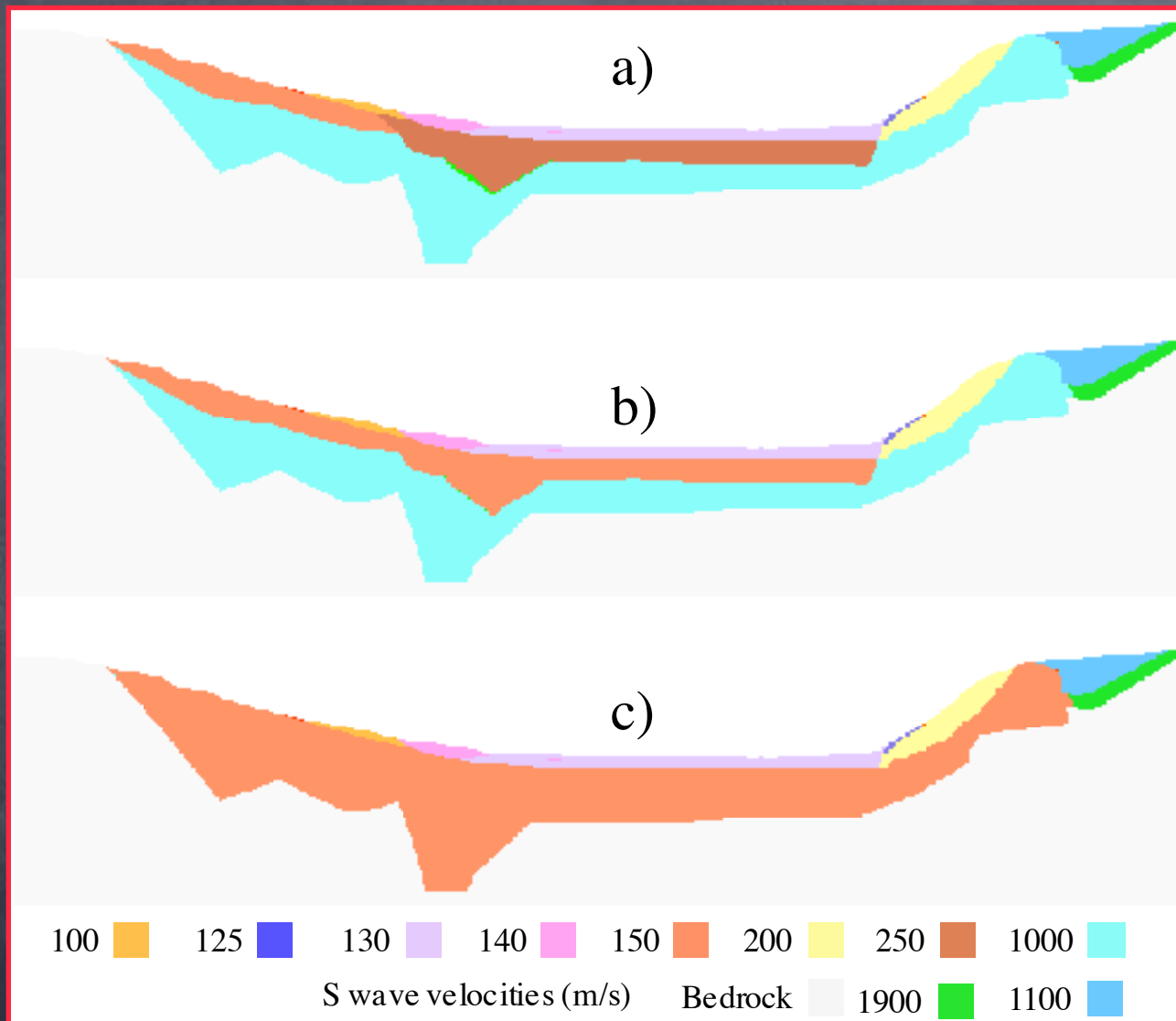
12 km deep at an epicentral distance of 30 km.

Parametric study 2nd - FS & RSR



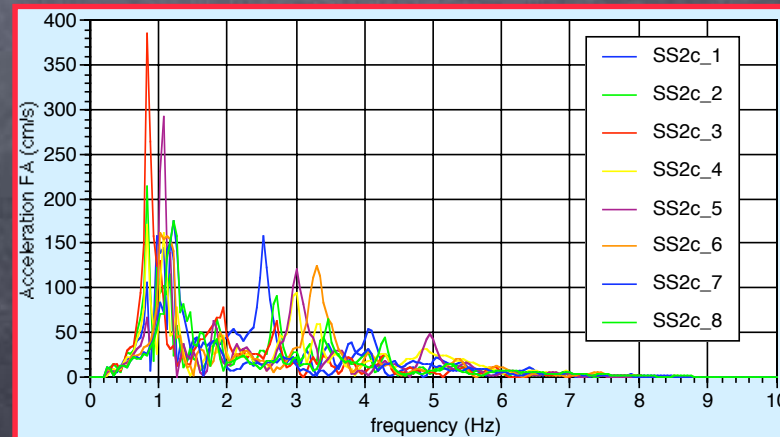
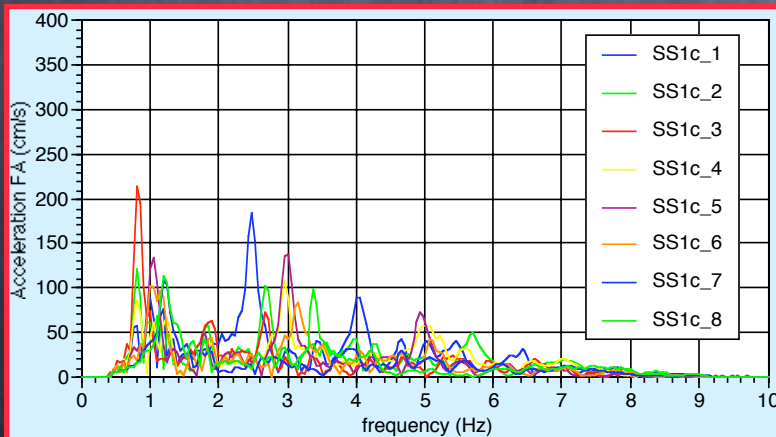
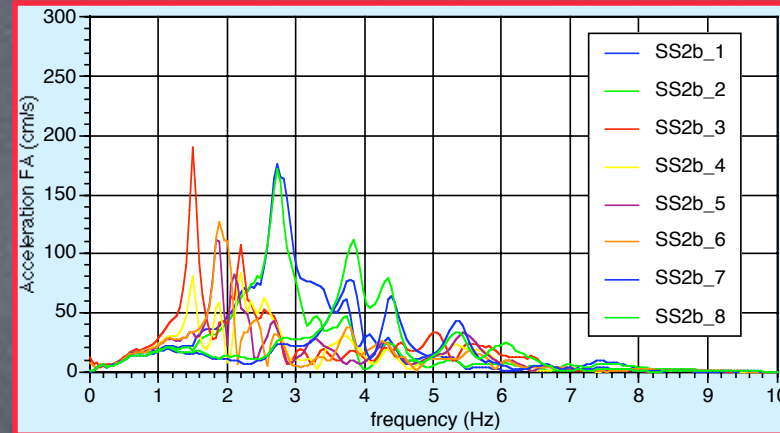
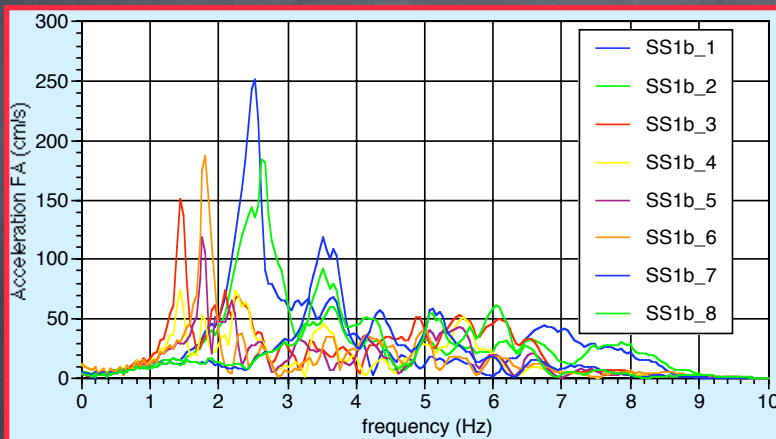
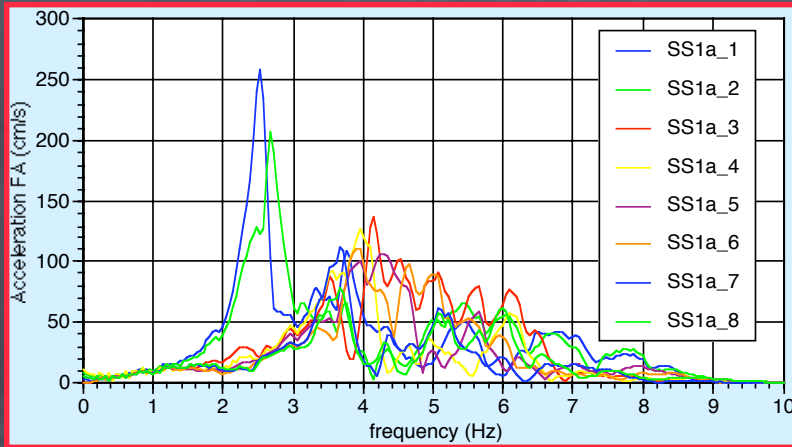
The results show that, even if the seismic energy around 1 Hz can be relevant (see bedrock curves), the local structure beneath the Warth bridge greatly amplifies the frequency components between 3 and 7 Hz, i.e. a frequency range not corresponding to the fundamental transverse mode of oscillation of the bridge (about 0.8 Hz)

Parametric study 3 - LMp towards 1Hz

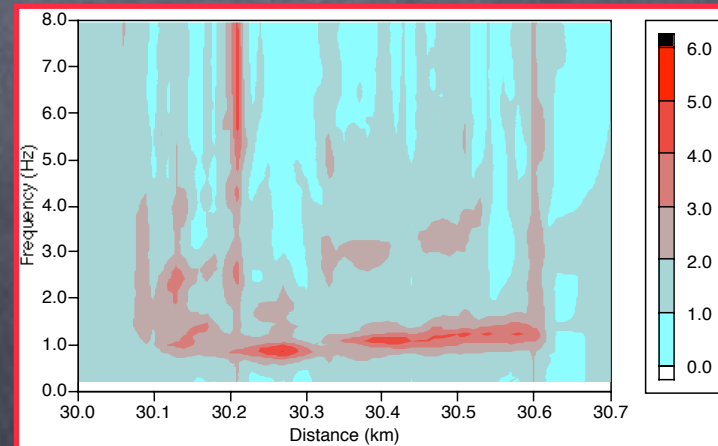
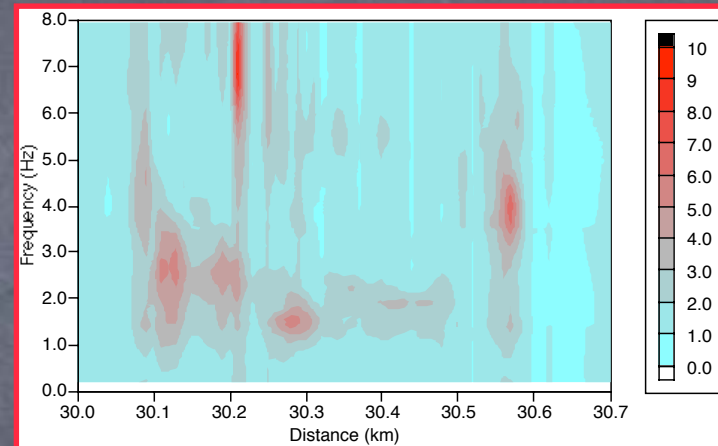
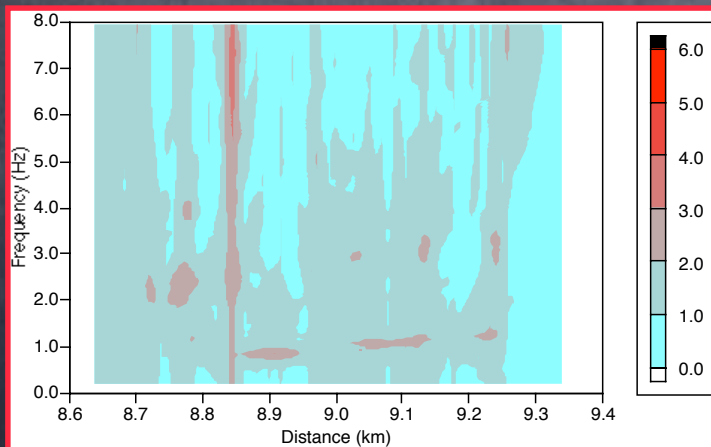
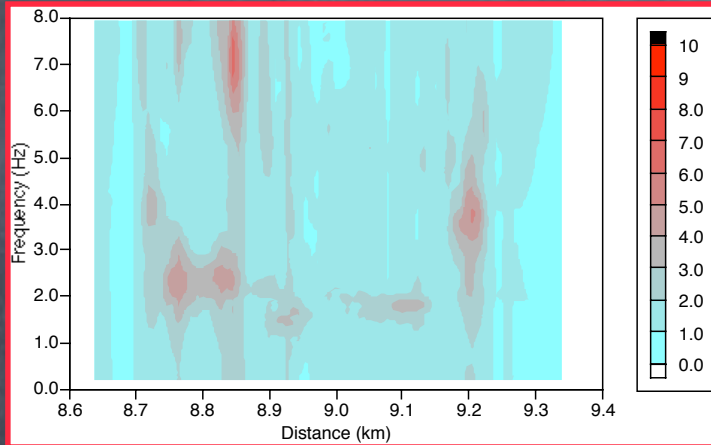
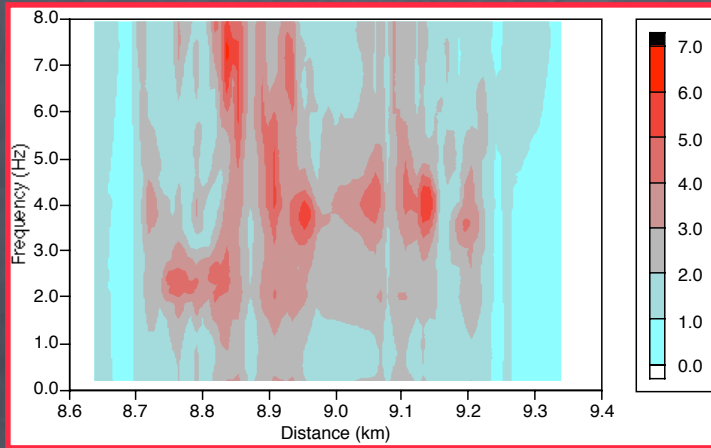


Local geotechnical models of Warth bridge section obtained lowering successively the S-wave velocities of the uppermost units

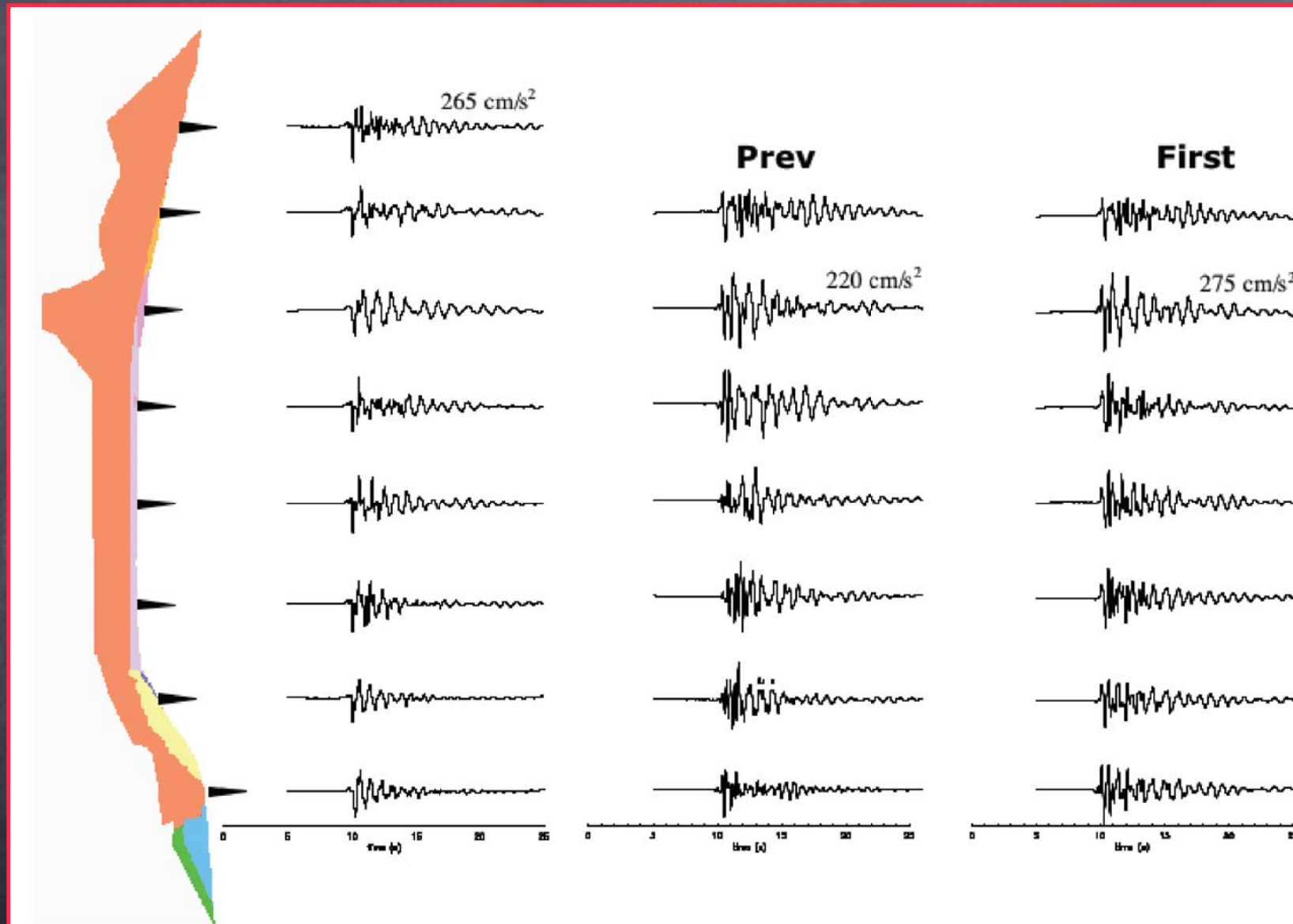
Parametric study 3rd FAS



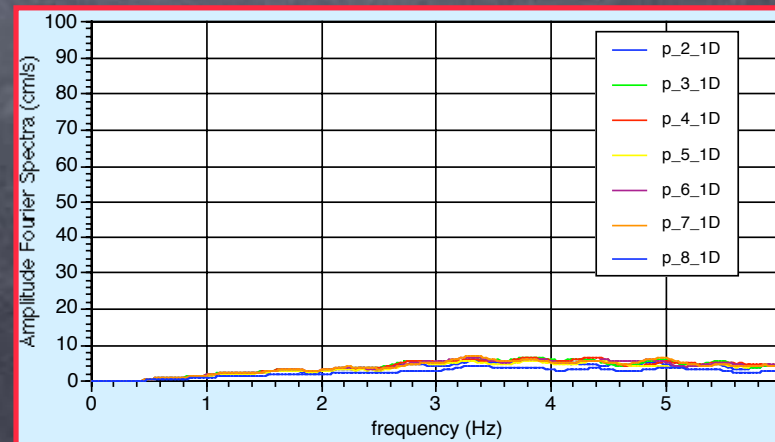
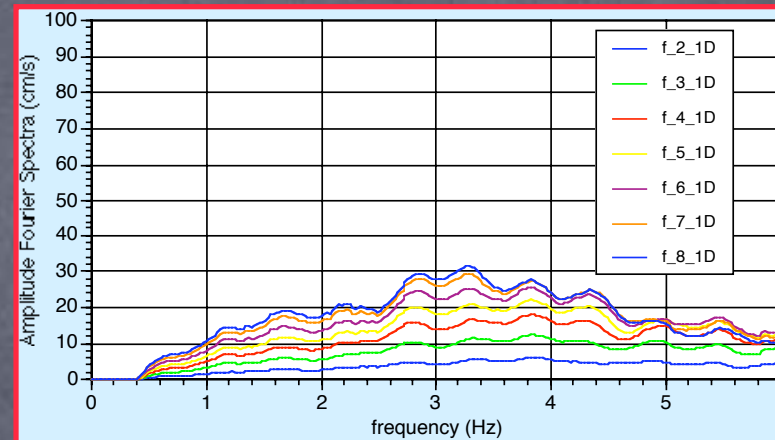
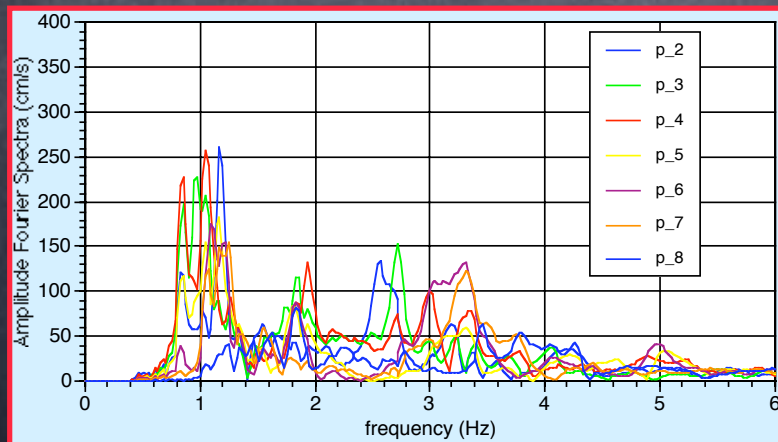
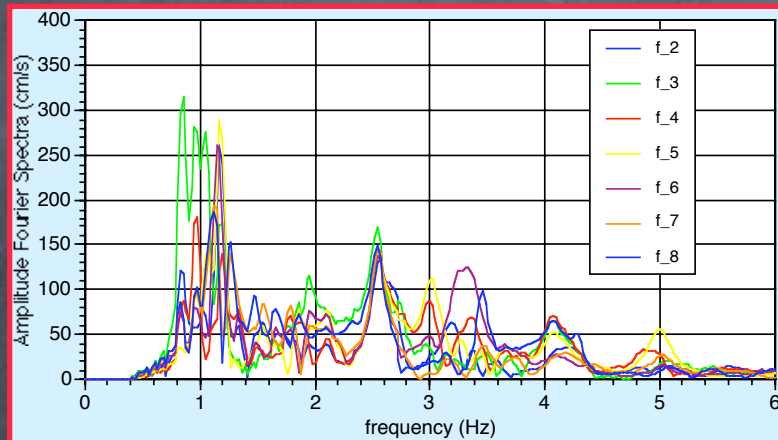
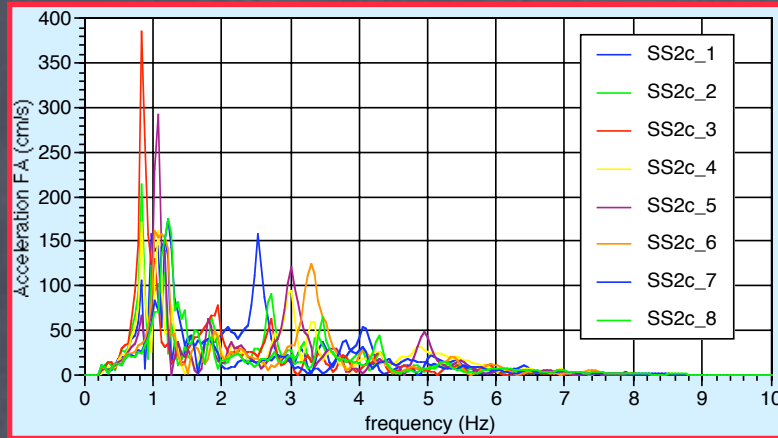
Parametric study 3rd RSR



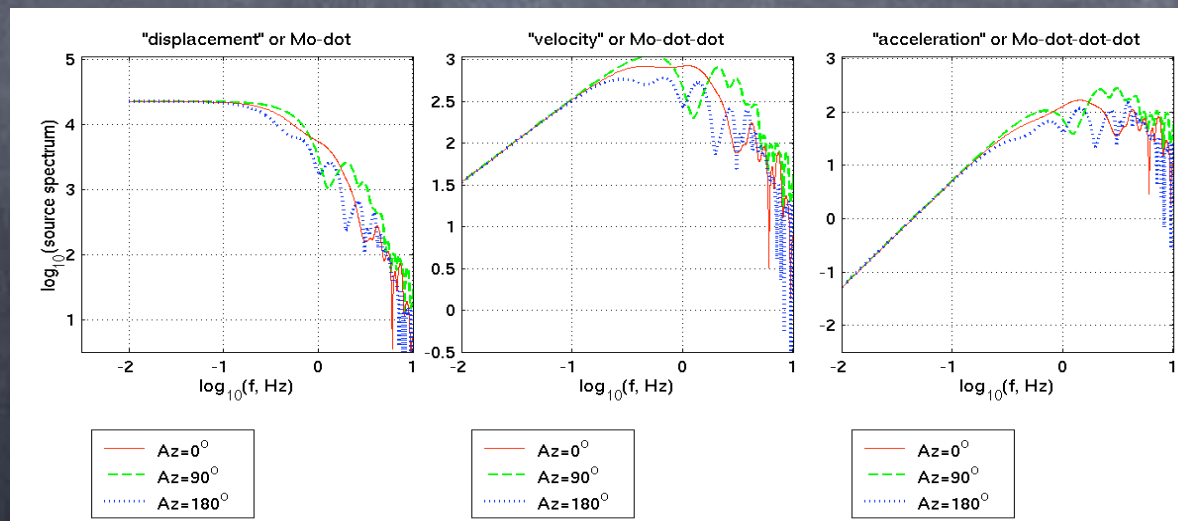
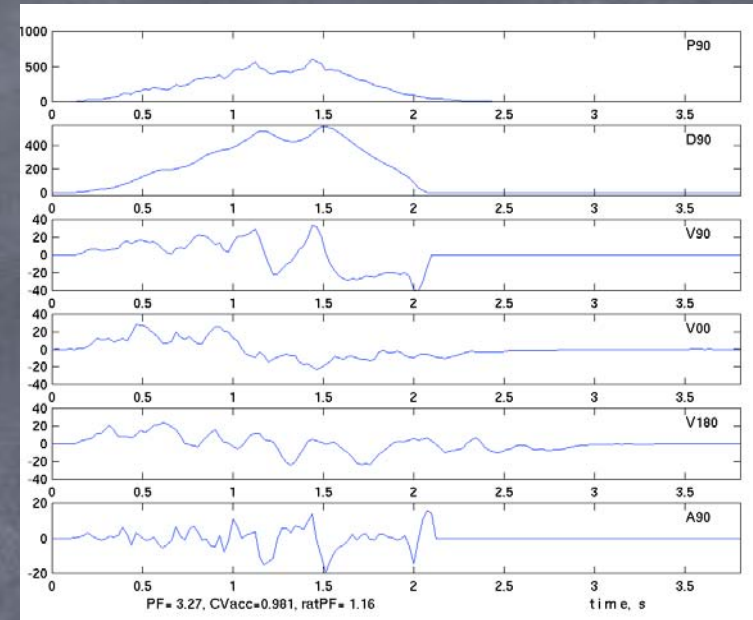
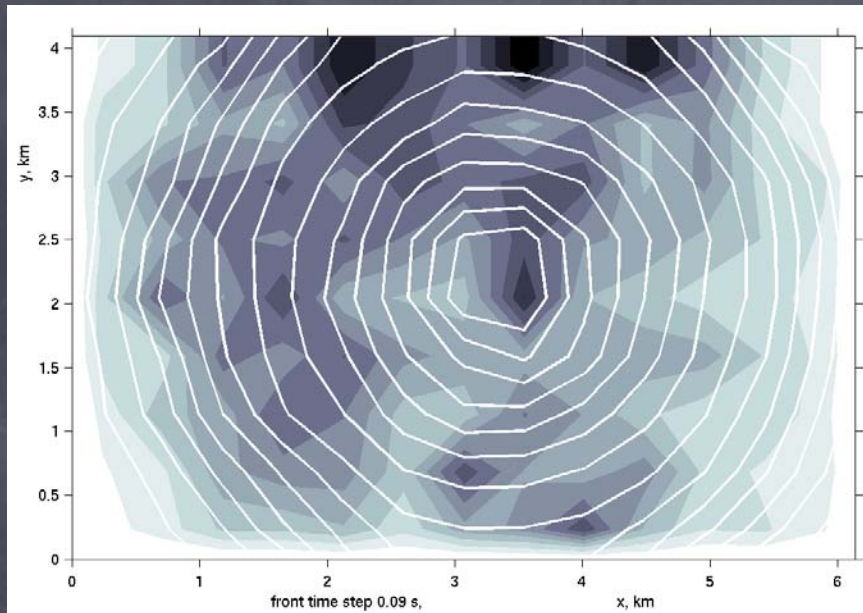
Synthetic accelerations and diffograms



Synthetic accelerations and diffograms FAS

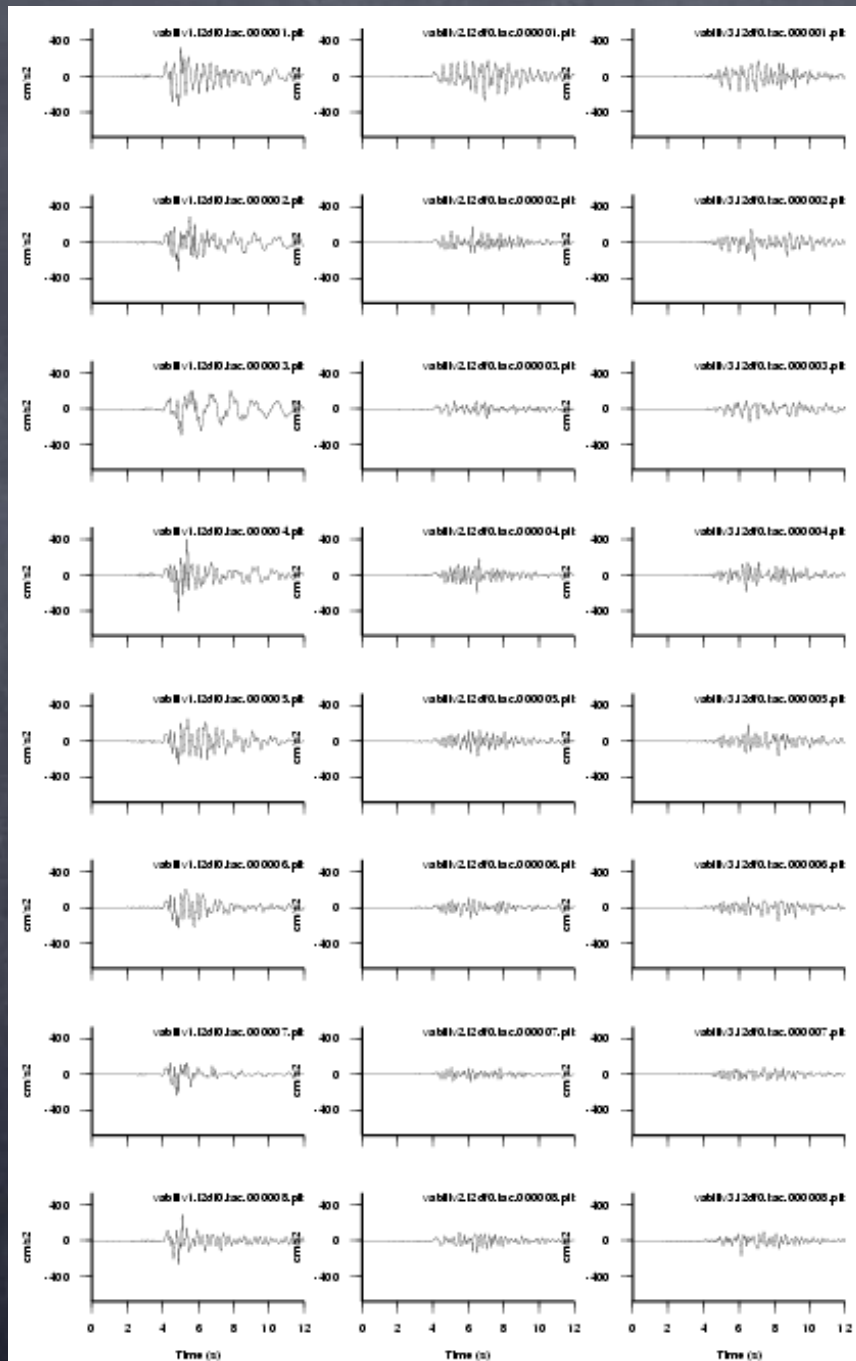


Parametric study 4 - ES_p towards directivity

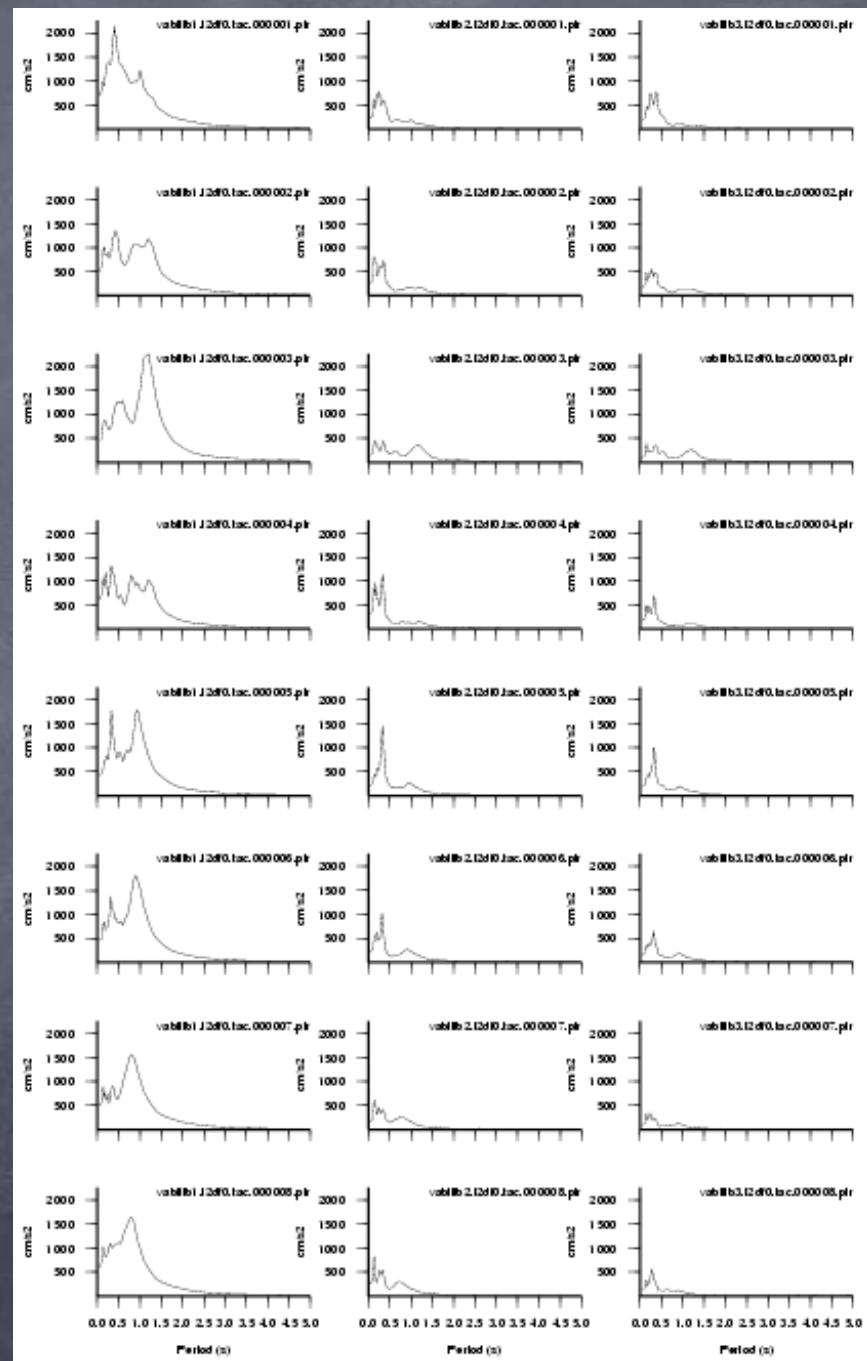


1st rupture model: bilateral at 3 positions

Accelerograms and response spectra

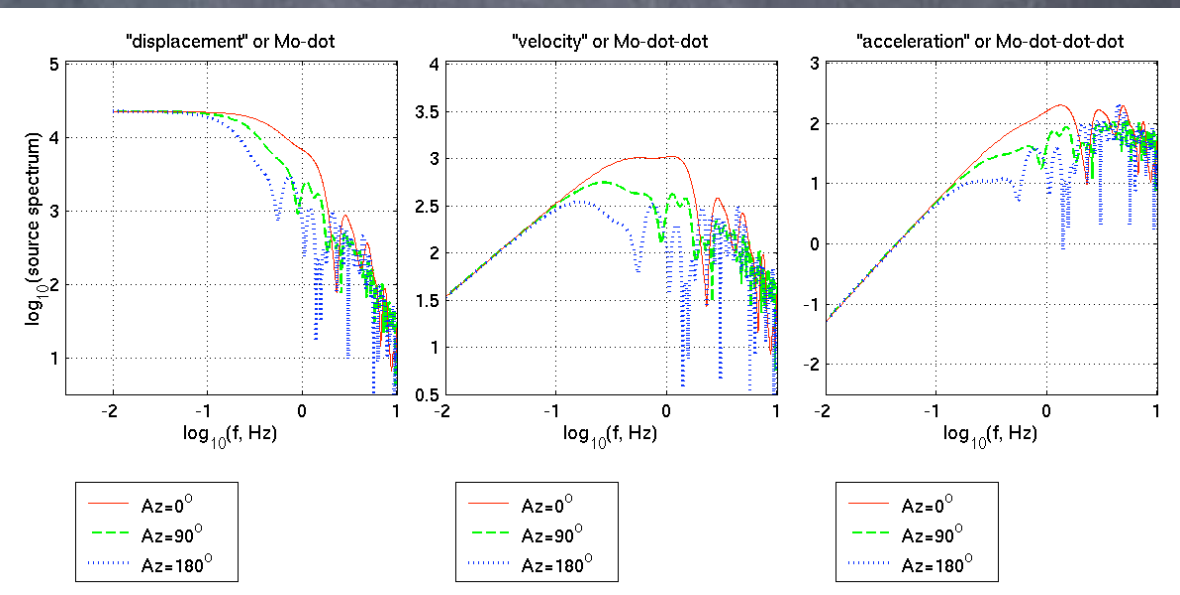
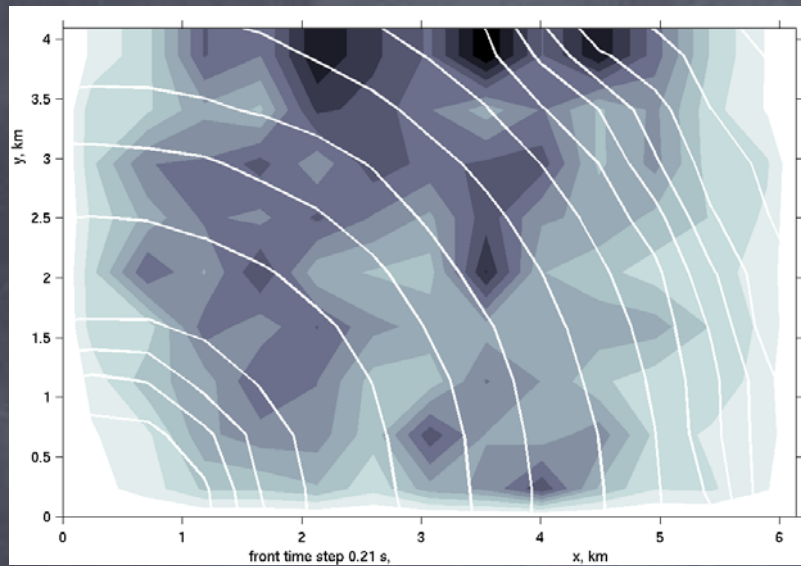


Parametric study 4 - ES



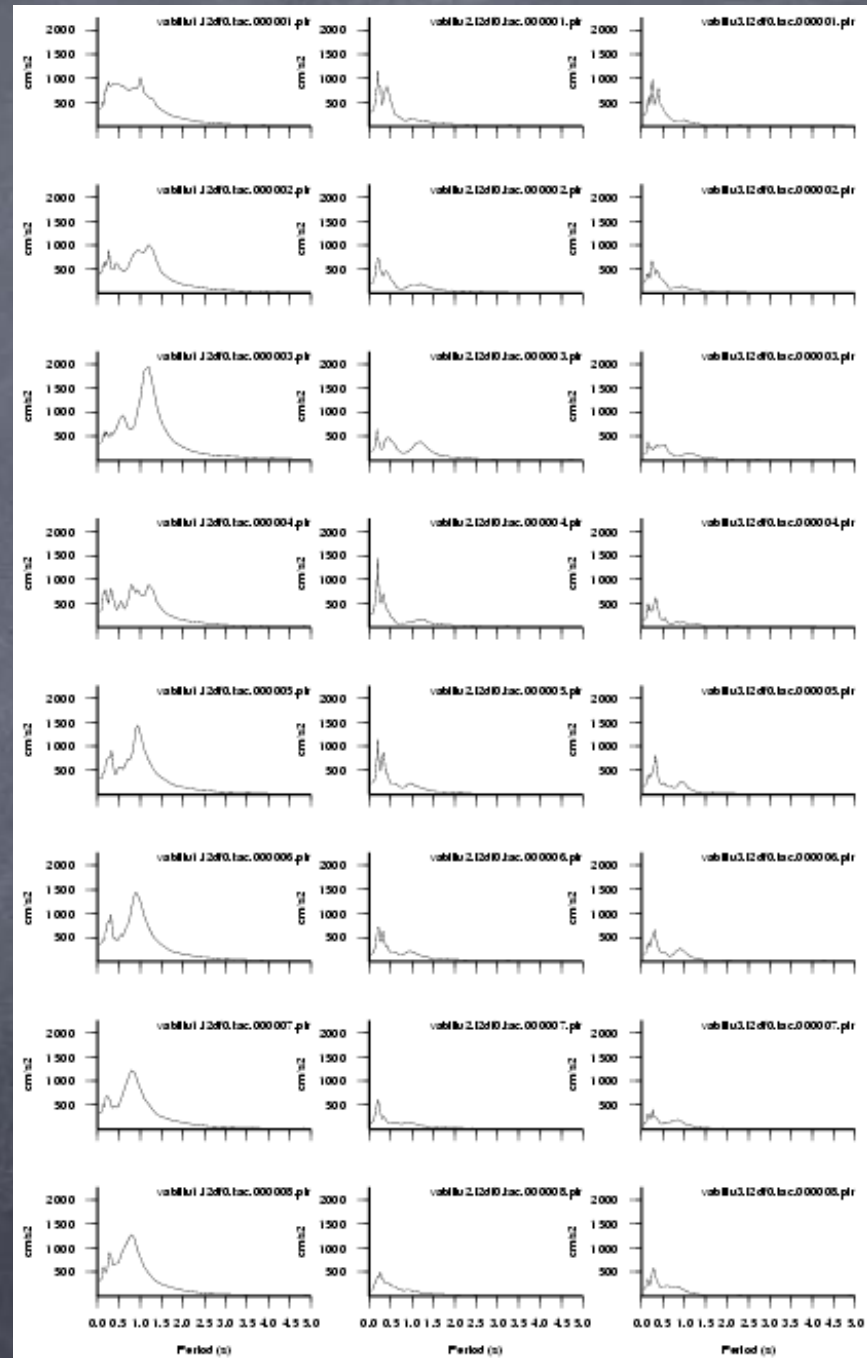
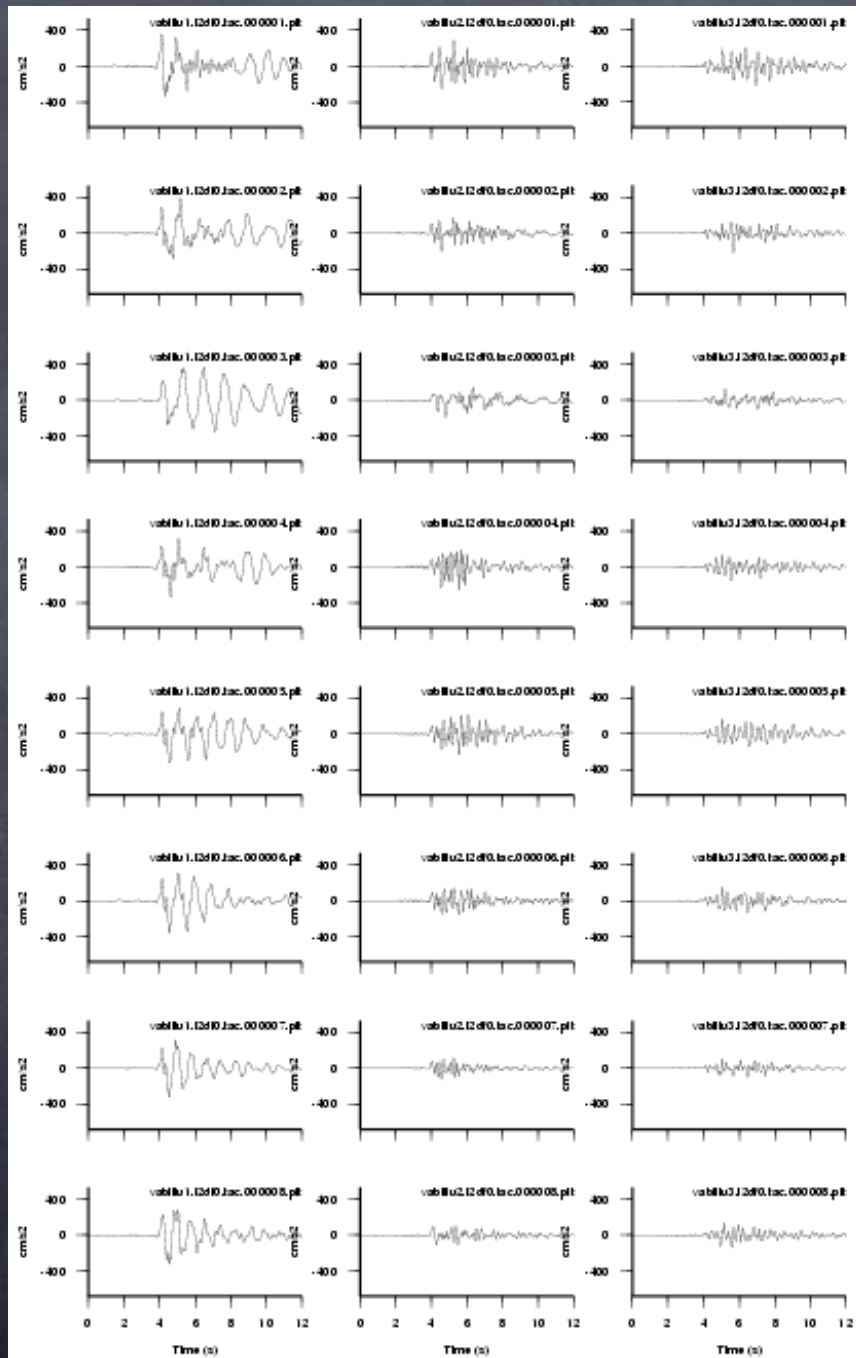
1st rupture model: bilateral at 3 positions

Parametric study 4 - ES_p towards directivity

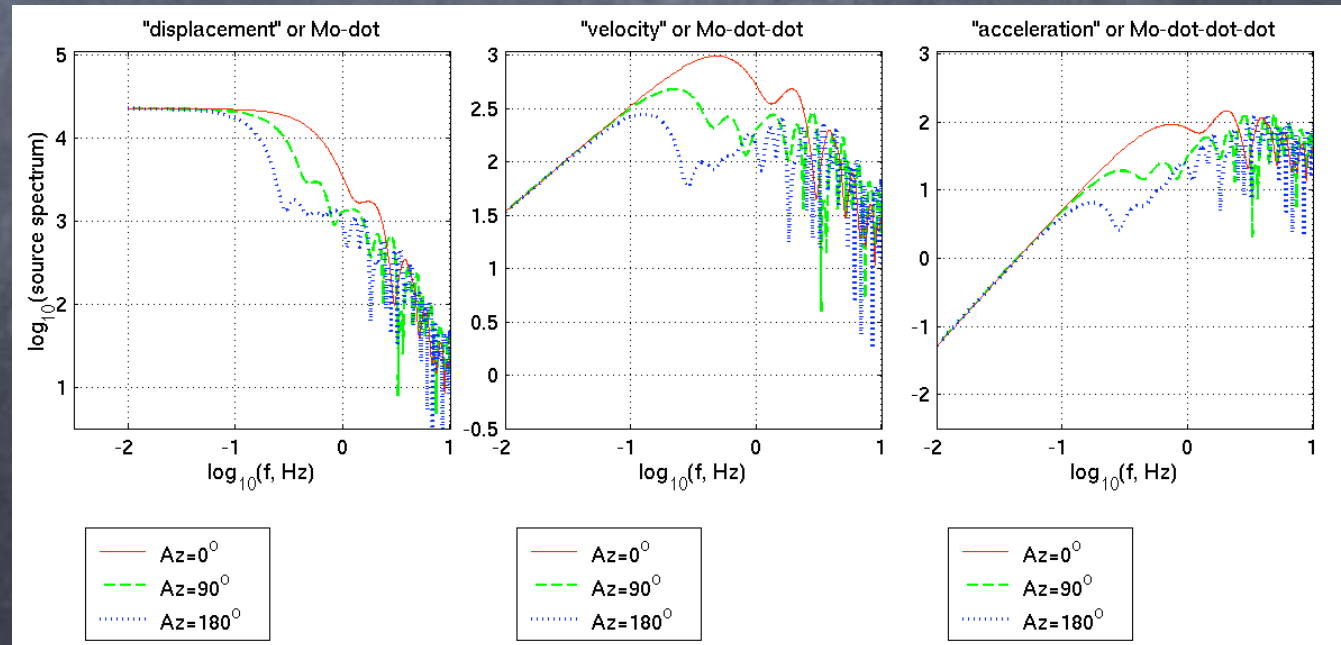
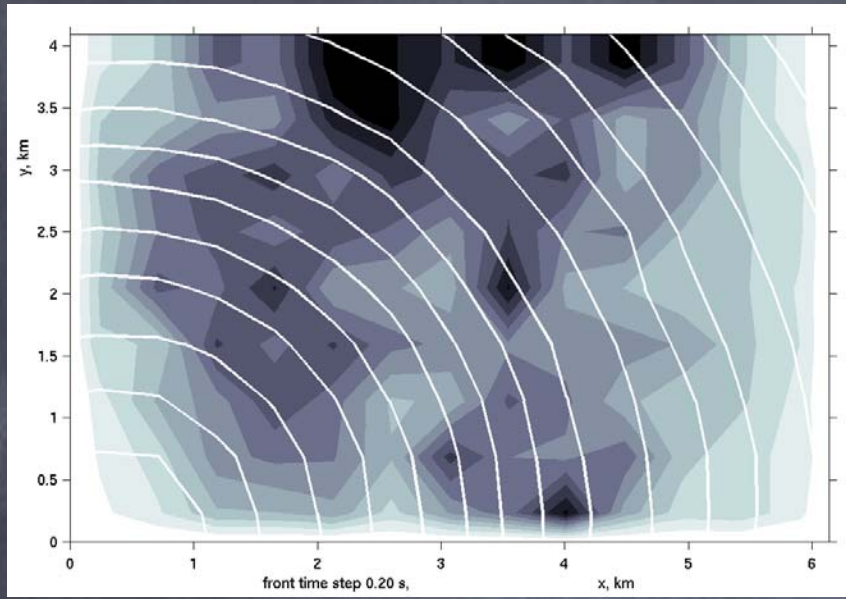


2nd rupture model: unilateral at 3 positions

Accelerograms and response spectra

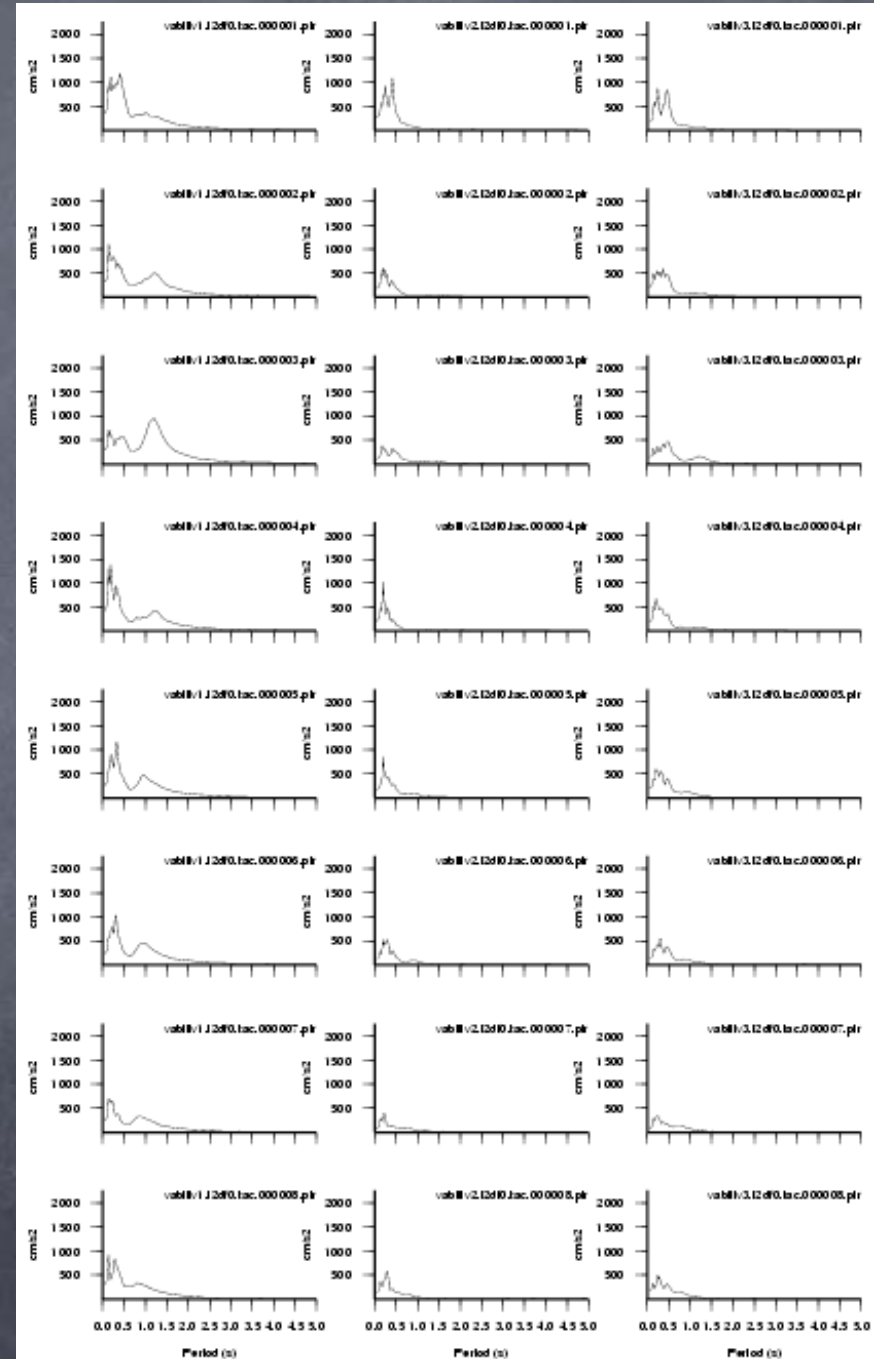
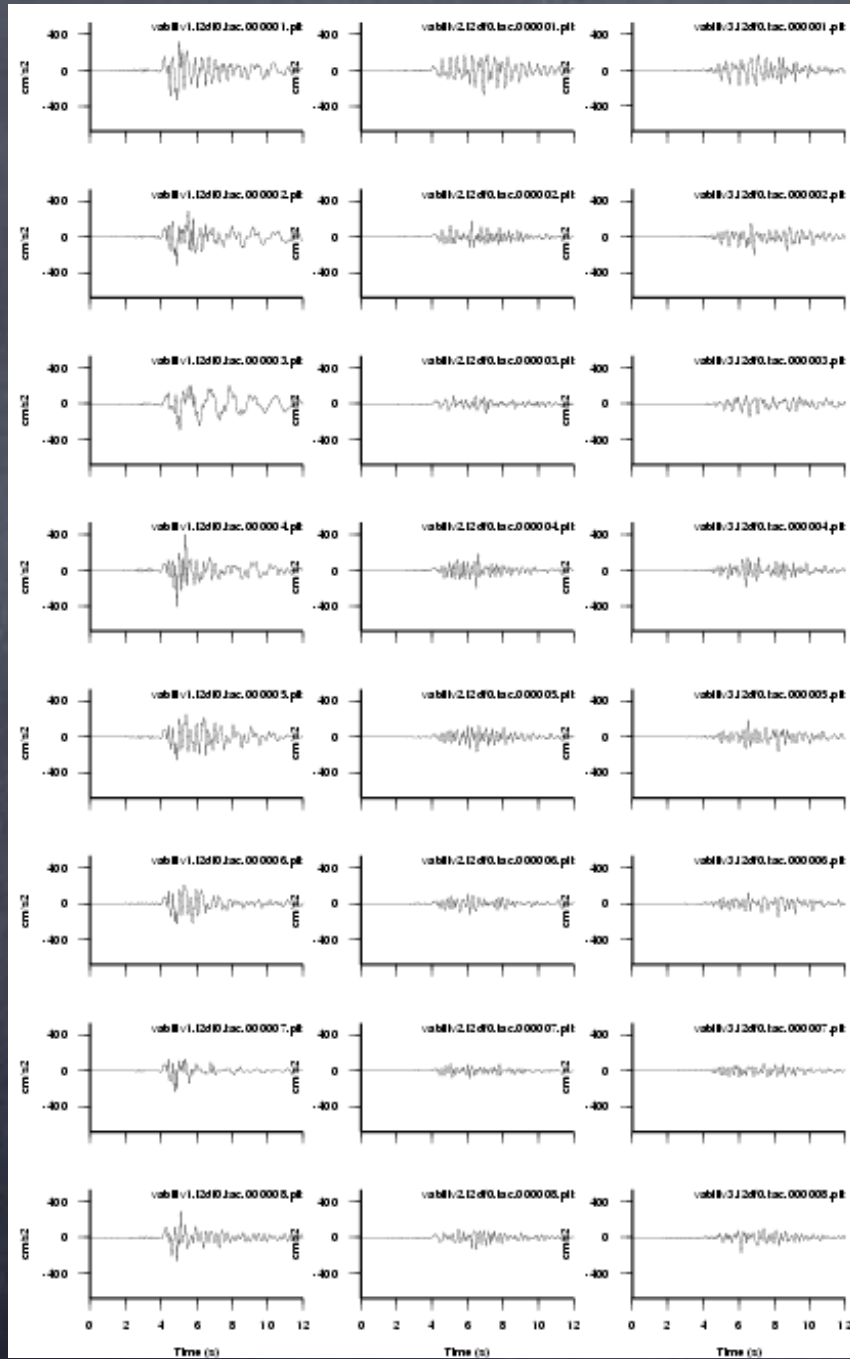


Parametric study 4 - ES_p towards directivity

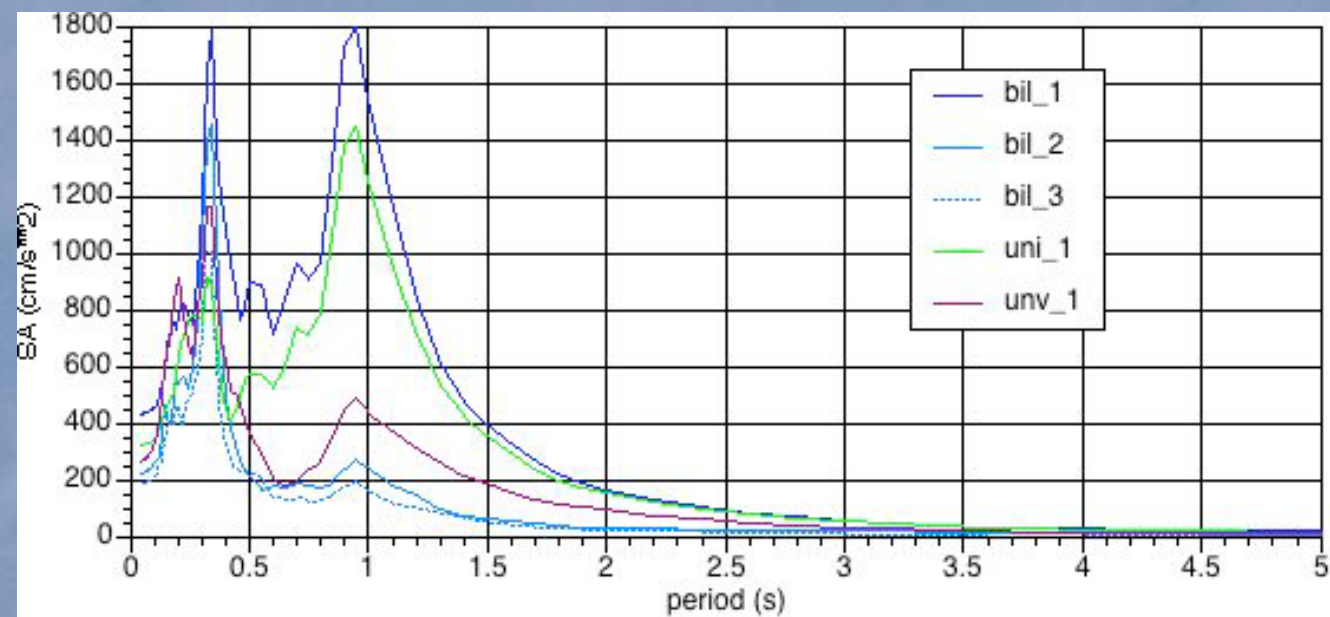
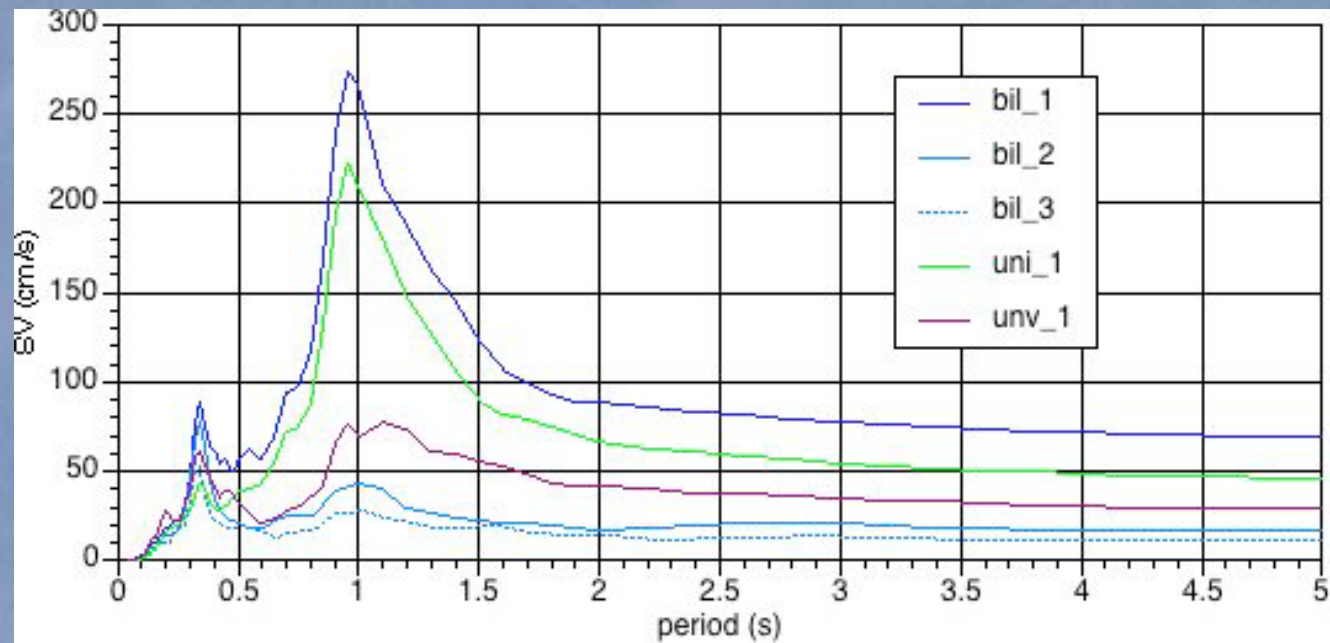


3rd rupture model: different v_p at 3 positions

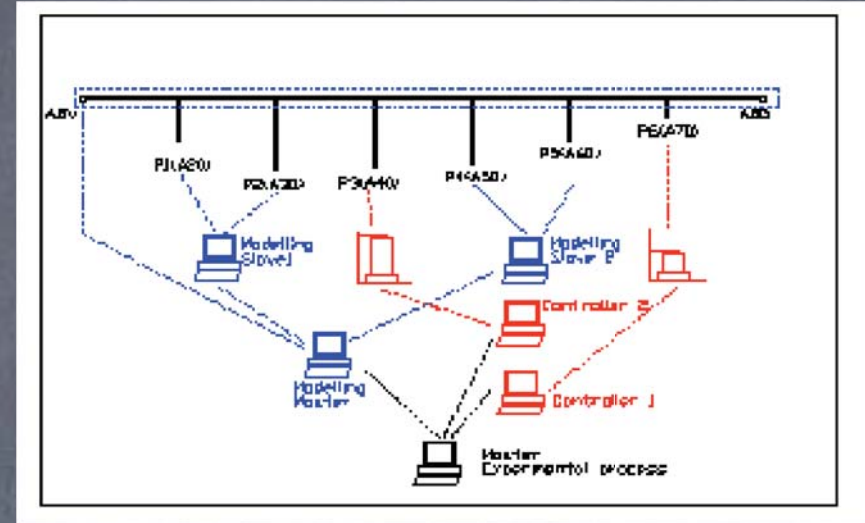
Accelerograms and response spectra



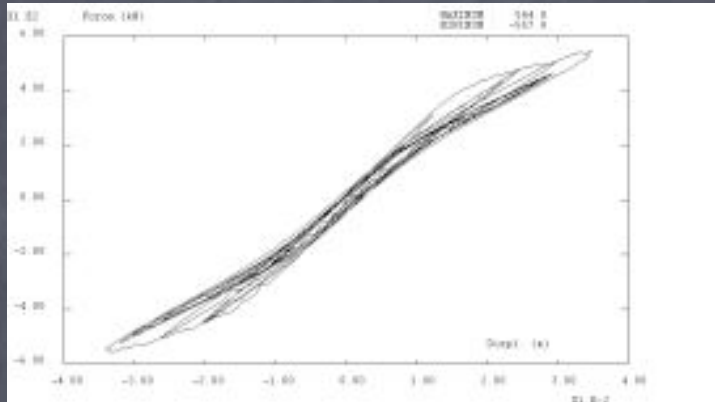
Parametric study - ES_p towards directivity



Implementation of PSD tests



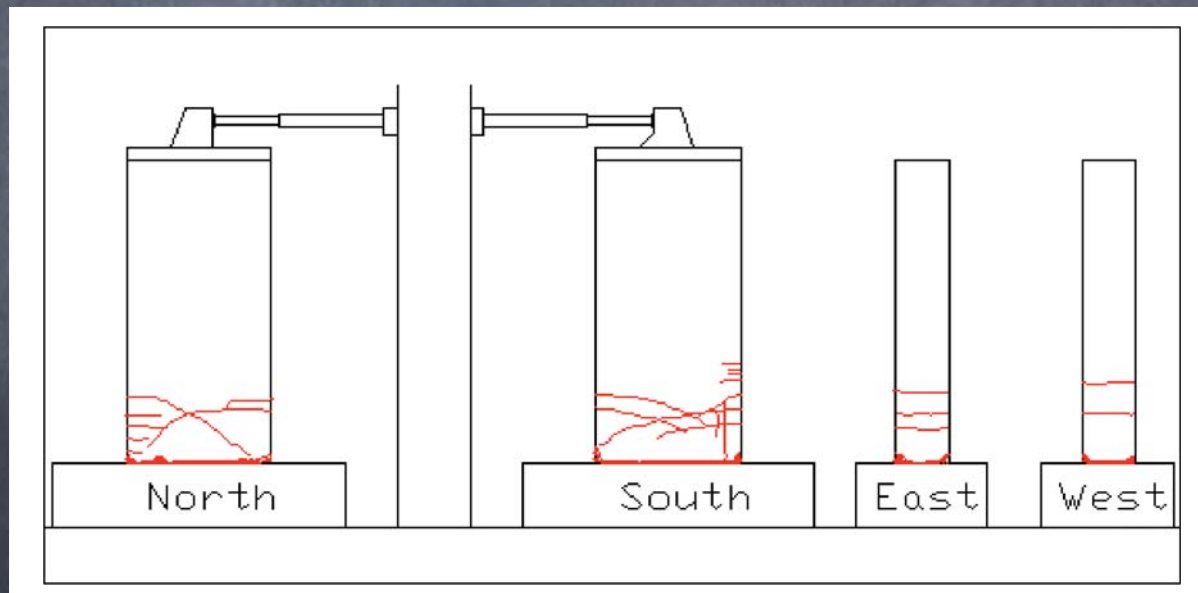
(a) physical piers in the lab, (b), schematic representation
(c) workstations running the PSD algorithm and controlling the test



Force-displacement for Low-level earthquake - experimental results Pier A40



Identification of insufficient seismic detailing. tall pier A40, buckling of longitudinal reinforcement at $h = 3.5\text{m}$



Damage pattern after the end of the High-Level Earthquake PSD test, short pier A70.

Conclusions - 1

- Different ground motions at the Warth site have been studied in order to define the maximum excitation in longitudinal and transverse direction, which are consistent both with the Maximum Credible Earthquake and with the Maximum Design.
- The main practical conclusion of our analysis, verified by laboratory experiments carried out at JRC-ISPR, is that the Warth bridge is likely to well stand the most severe seismic input compatible with the seismic regime of the Eastern Alps.
- With the parametric study we have defined a seismic source-Warth site configuration that provides a set of signals whose seismic energy is concentrated around 1 Hz, frequency that corresponds approximately to that of the fundamental transverse mode of oscillation of the bridge.

Conclusions - 2

- The results show that lateral heterogeneity can produce strong spatial variations in the ground motion even at small incremental distances.
- Such variations can hardly be accounted for by the stochastic models commonly used in engineering practice.
- In absolute terms, the differential motion amplitude is comparable with the input motion amplitude when displacement, velocity and acceleration domains are considered.
- On the base of the existing empirical regression relations between Intensity and peak values of ground motion a general result of our modeling is that the effect of the differential motion can cause an increment greater than one unit in the seismic intensity experienced by the bridge, with respect to the average intensity affecting the area where the bridge is built.

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