The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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

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PSHA and hazard scenarios: groundshaking modelling for seismic input

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ICTP/IAEA Advanced Workshop on Earthquake Engineering for Nuclear Facilities

PSHA and hazard scenarios: groundshaking modelling for seismic input

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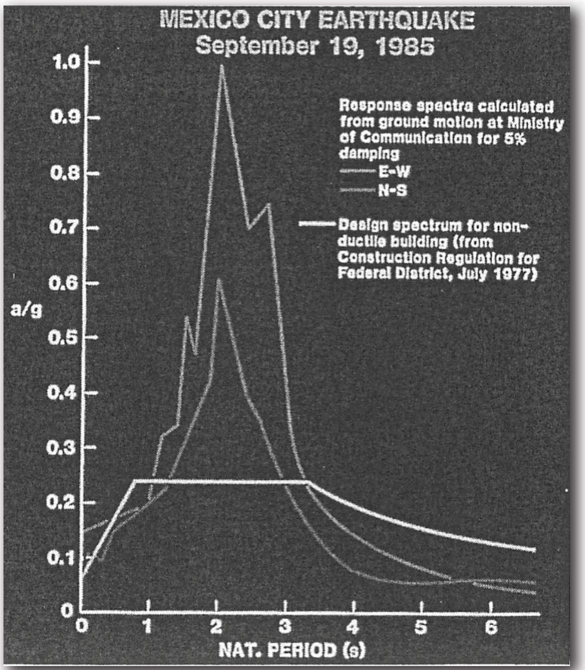
the road to (earthquake) safety...

Know the input - Bound the output...

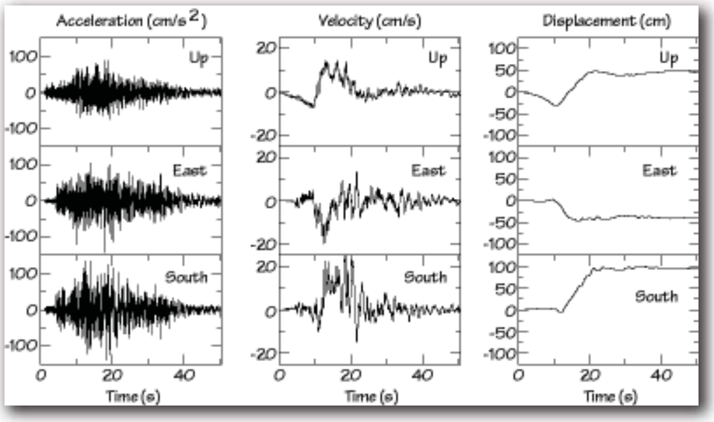


Mitigate the difference...

Road map

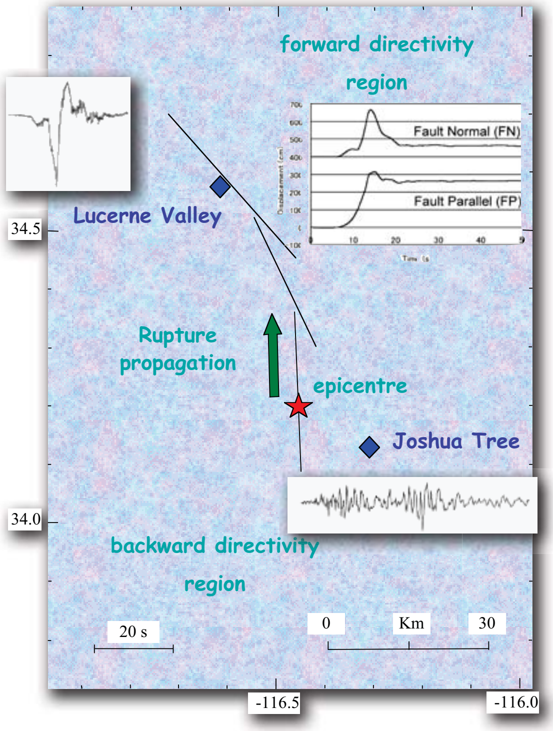
- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology
- Groundshaking scenarios modelling
  - Case Studies

Source effects...



Michoacan, 1985

Fling & Directivity
aka
Near-field (& source)

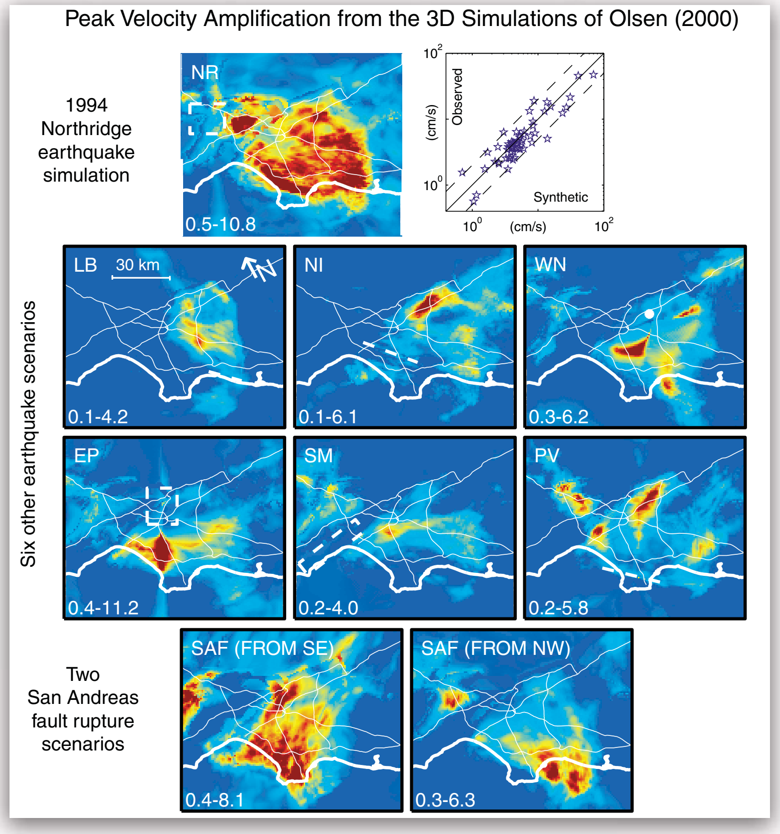


Landers, 1992

Amplification patterns...

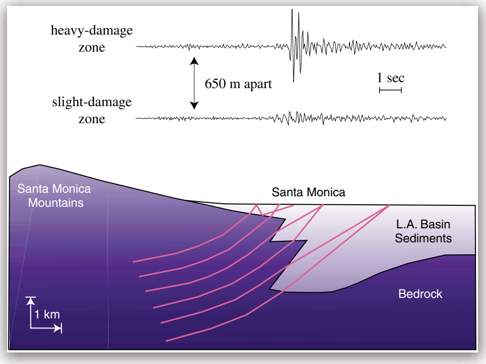
....may vary greatly among the earthquake scenarios, considering different source locations (and rupture ...)

SCEC Phase 3 Report



Important issues in SRE

- Near surface effects: impedance contrast, velocity
  - geological maps, v_{30}
- Basin effects
  - Basin-edge induced waves
  - Subsurface focusing



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

PGA as a demand parameter…

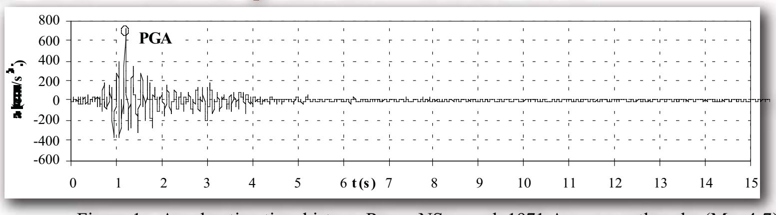


Figure 1 – Acceleration time history. Rocca NS record. 1971 Ancona earthquake (M_L=4.7)

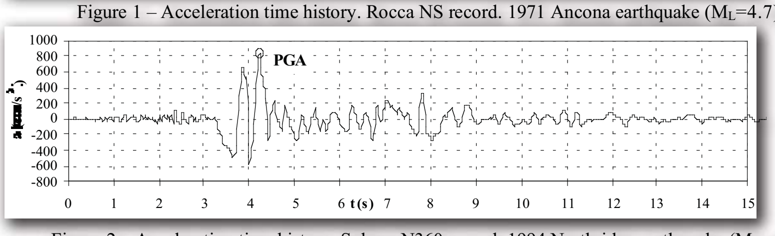
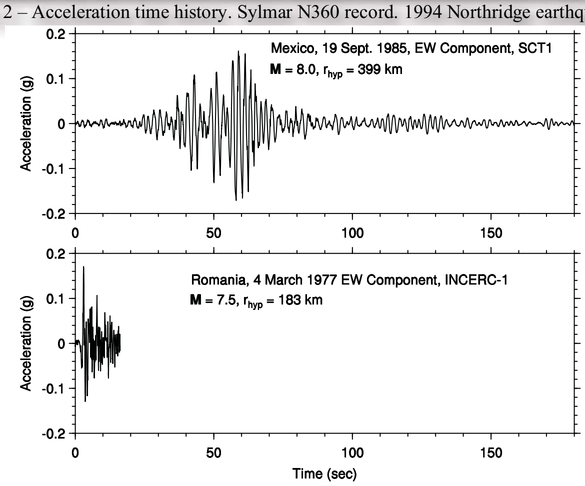


Figure 2 – Acceleration time history. Sylmar N360 record. 1994 Northridge earthquake (M_w=6.7)



SHA dualism

	Deterministic			**Probabilistic**
Risk mitigation decision	Emergency response			Design/Retrofit
Seismic environment	Next to active fault	High hazard, plate margin	Moderate hazard, anywhere	Low hazard, midplate
Scope of the project	Regional risk		Multiple properties lifelines	Specific site
	Qualitative			**Quantitative**

Modified from: Mc Guire, 2001

SHA

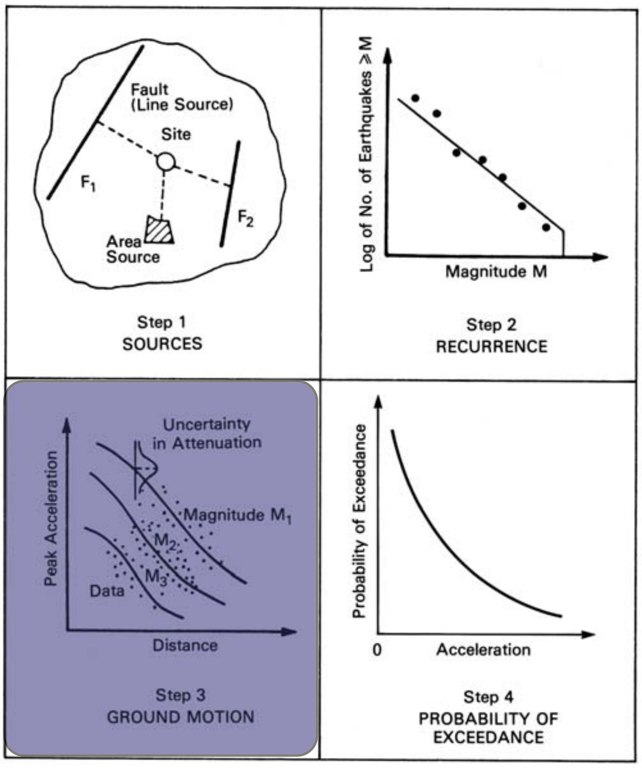


FIGURE 10.2 Basic steps of probabilistic seismic hazard analysis (after TERA Corporation 1978).

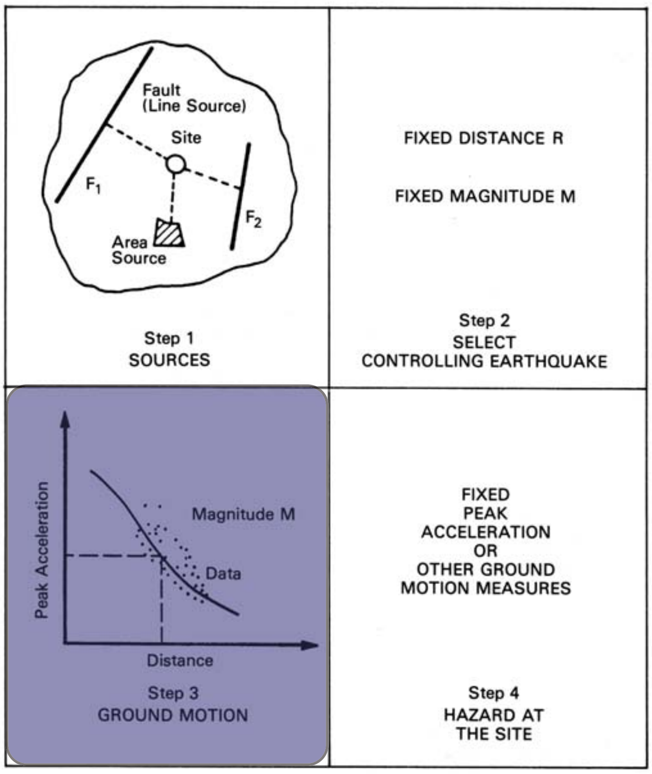


FIGURE 4.1 Basic steps of deterministic seismic hazard analysis (after TERA Corporation 1978).

Probabilistic and Deterministic procedures (after Reiter, 1990)

PBDE

SHA produces response spectral ordinates (or other intensity measures) for each of the annual probabilities that are specified for performance-based design.

In PBDE, the ground motions may need to be specified not only as intensity measures such as response spectra, but also by suites of strong motion time histories for input into time-domain nonlinear analyses of structures.

It is necessary to use a suite of time histories having phasing and spectral shapes that are appropriate for the characteristics of the earthquake source, wave propagation path, and site conditions that control the design spectrum.

Modern PSHA & DSHA dualism

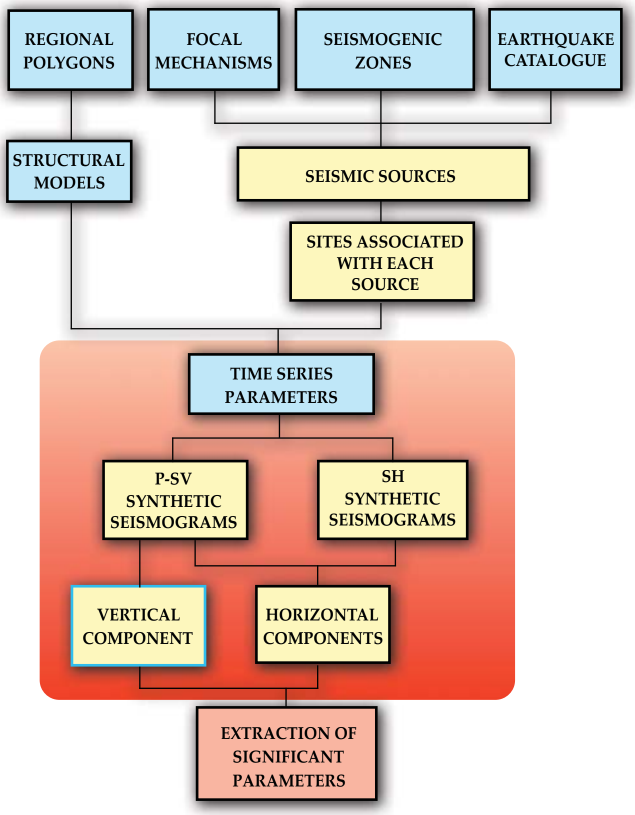
PSHA	Waveform modelling
Accounts for all potentially damaging earthquakes in a region	Focus on selected controlling earthquakes
(Single) parameter	Complete time series
Deeply rooted in engineering practice (e.g. building codes)	Dynamic analyses of critical facilities

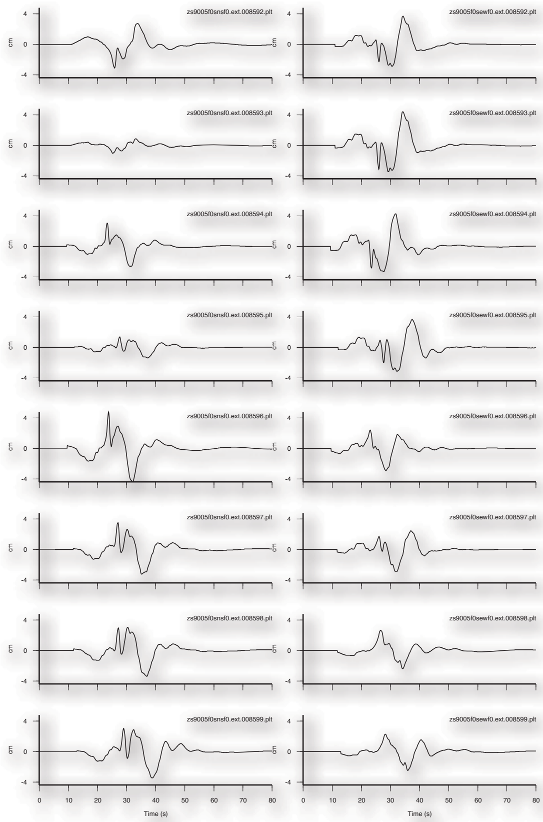
Deaggregation, recursive analysis → ← Study of attenuation relationships

Multiscale Neo-deterministic Hazard Scenarios

Regional seismic hazard scenarios (ground motion at bedrock)

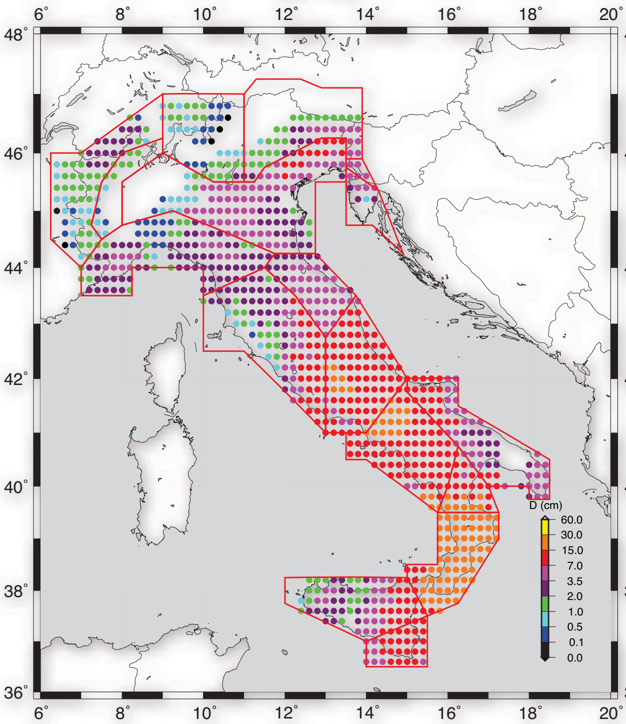
Regional Scale - Seismograms



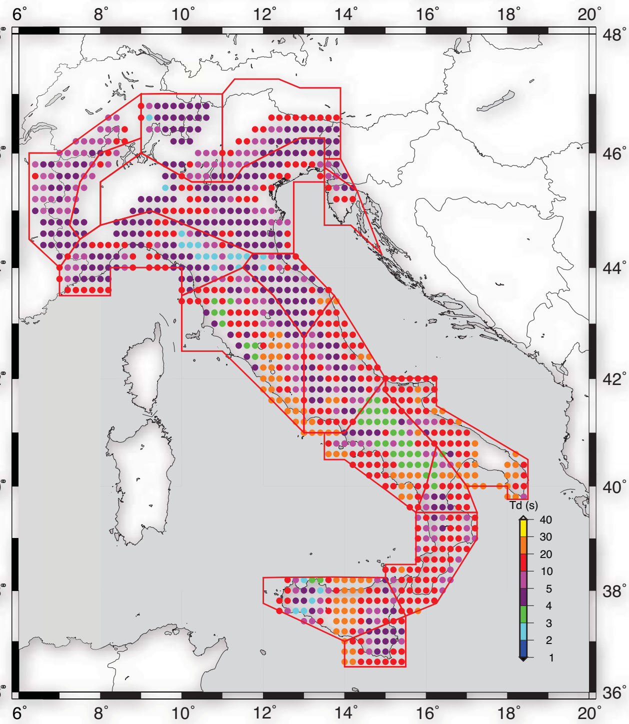


Displacement - Italy

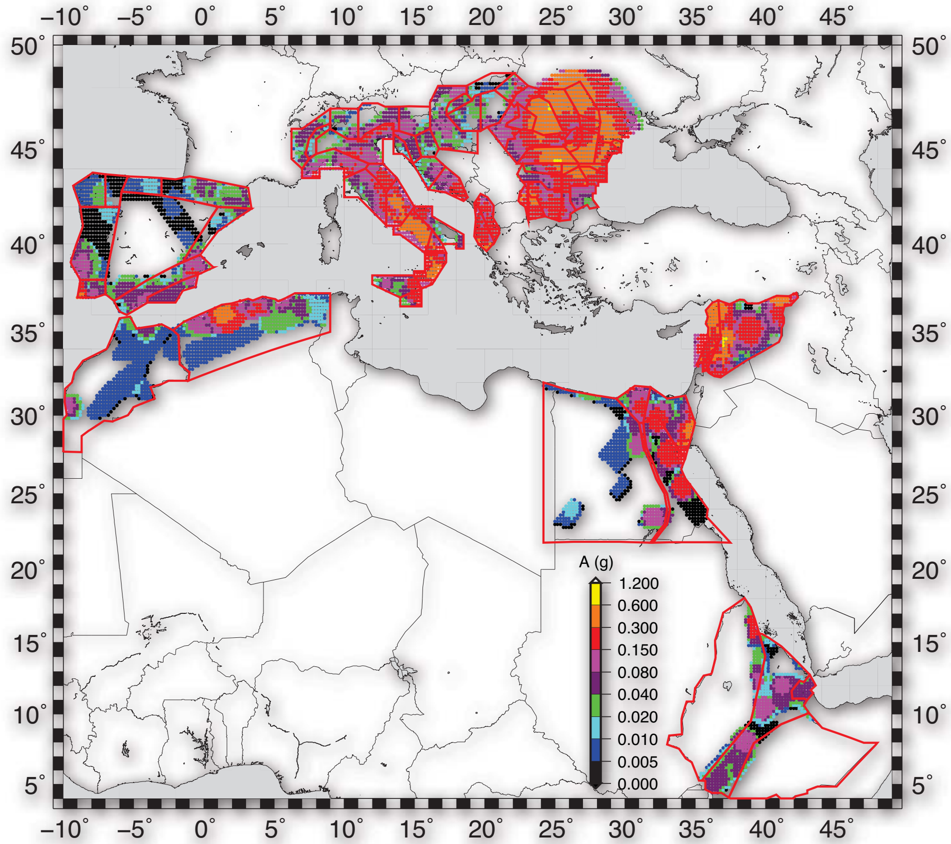
Amplitude of Peaks from Time Series (1Hz)



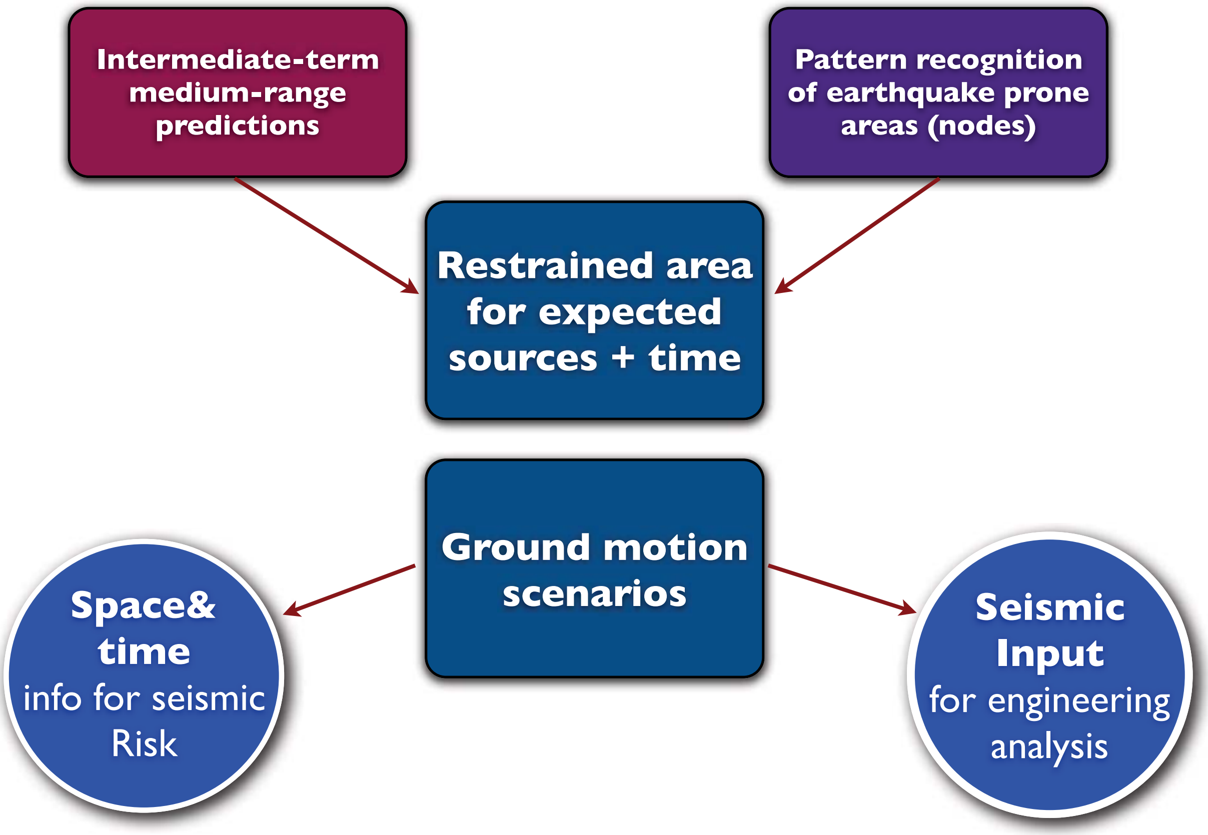
T of Peaks from Fourier Spectra



The procedure has been applied to several countries in the world. Here the map of DGA is shown



Integrated Neo-Deterministic Hazard



Road map

- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology (Source effects)

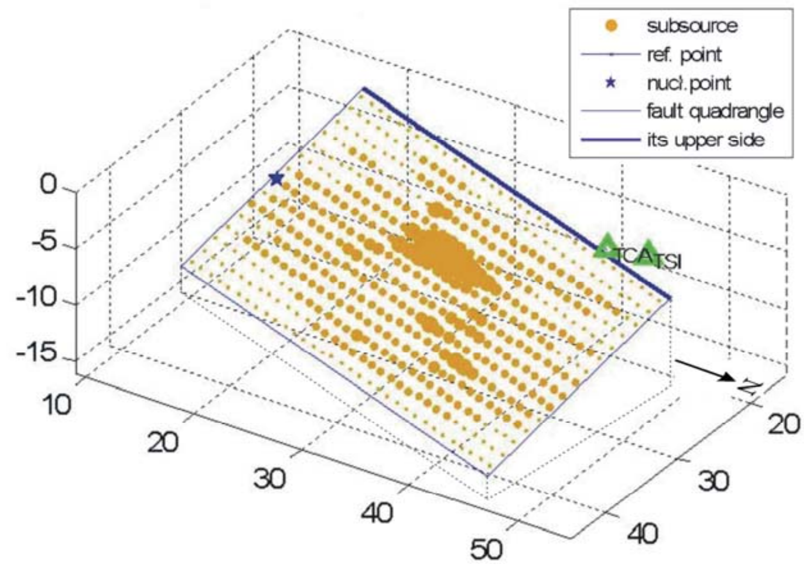
GUSEV A. A, Pavlov V, Romanelli F., Panza G. (2008).

Low-frequency seismic ground motion at the pier positions of the planned Messina straits bridge for a realistic earthquake scenario.
In: 2008 Seismic Engineering Conference commemorating the 1908 Messina and Reggio Calabria Earthquake. MELVILLE, NEW YORK: AIP, vol. 1020, p. 362-369, ISBN/ISSN: 978-0-7354-0542-4/0094-243X.

Pier Positions of the Planned Messina Straits Bridge

1908 scenario

To model the 1908 event, we assume a M_w=7 earthquake, with a 40x20 km rectangular fault, and pure reverse dip-slip. The horizontal upper side of the rectangle is at 3-km depth, and the N corner of the rectangle is just between the piers.



3D view: fault model geographical location together with the position of the two piers: Torre Calabria, TCA and Torre Sicilia, TSI. Star is the rupture nucleation point.

A typical simulation is made in three steps.

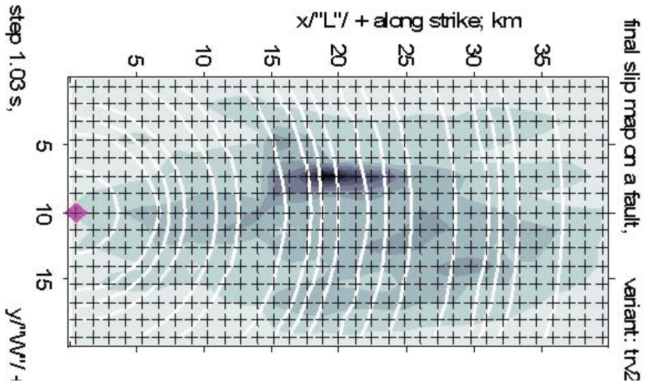
- The fault motion is initially (first step) represented by the time history of slip in each of the subfaults and by the distribution of the final seismic moment among the subsources (forming "asperities"), both generated as lognormal random functions. The time histories are then filtered in order to fit a chosen source spectral model.

- The parameters that are conditioning the random functions can be based on the bulk of published fault inversions, or reproduced from an earlier successful attempt to simulate ground motions in the epicentral zone of the 1994, M=6.7 Northridge, California, earthquake.

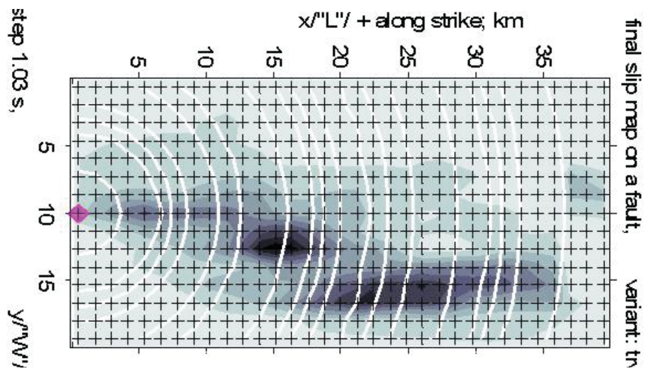
- In the second step, the Green functions (for each subfault and pier combination) are calculated for a layered halfspace model of the pier foundation stratigraphy, using an advanced Green function calculator, that allows an accurate calculation over the entire relevant frequency band including static terms. Finally (third step), the 3-components of the strong ground motion are obtained at the two piers through convolution and summation over the different subsources.

Rupture histories

Variant 222

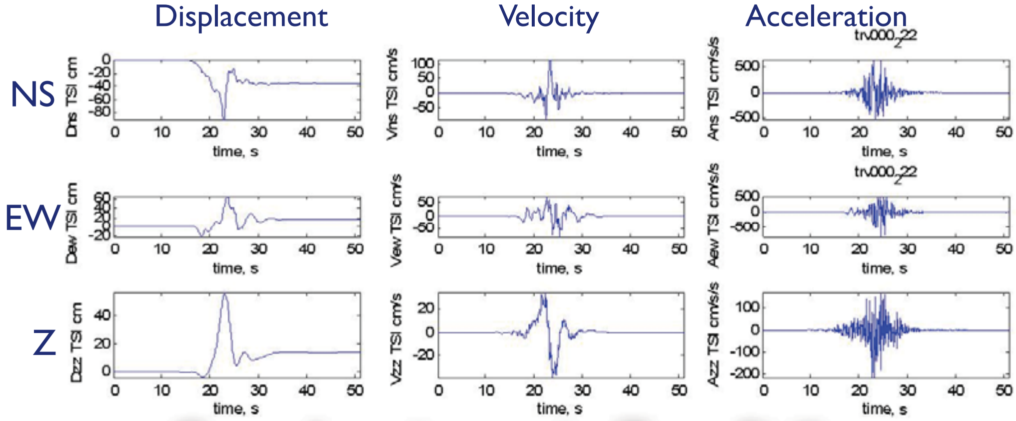


Variant 224



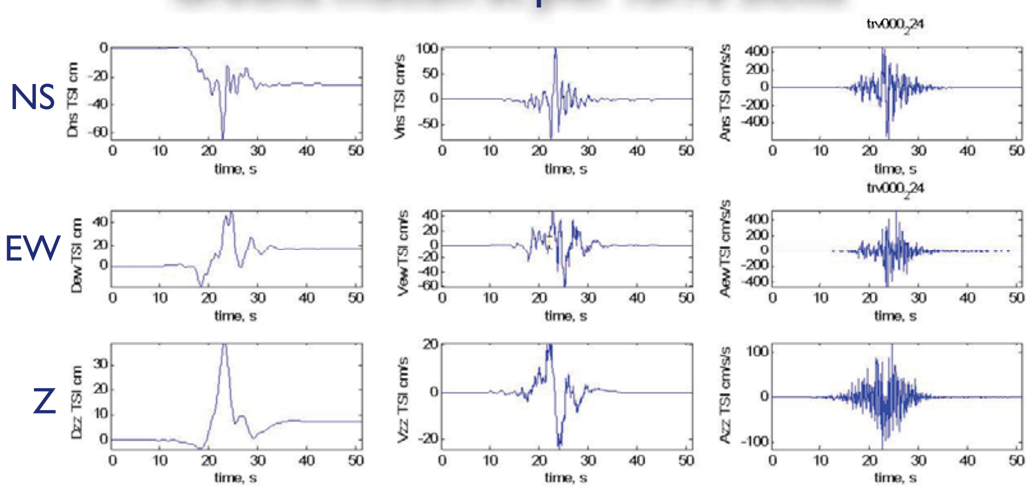
Slip or $M_o(x,y)$ distribution by levels of grey. Diamond is the nucleation point, and white contours are rupture front positions every 1.03 s

Displacement | Velocity | Acceleration



a) variant 222

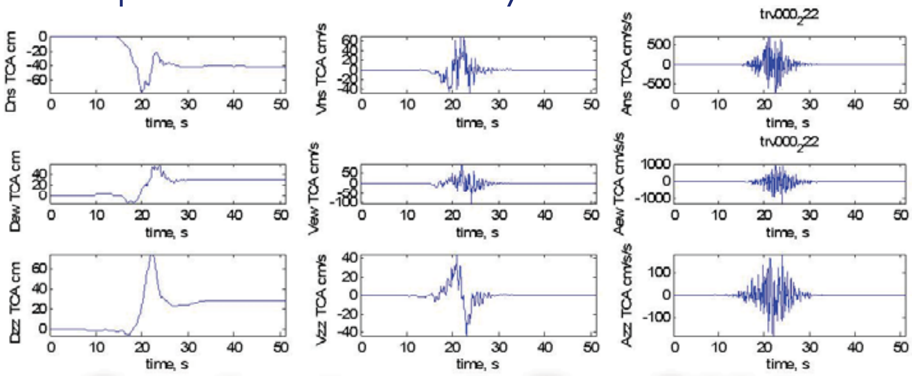
Ground motion at pier Torre Sicilia



b) variant 224

Displacement | Velocity | Acceleration

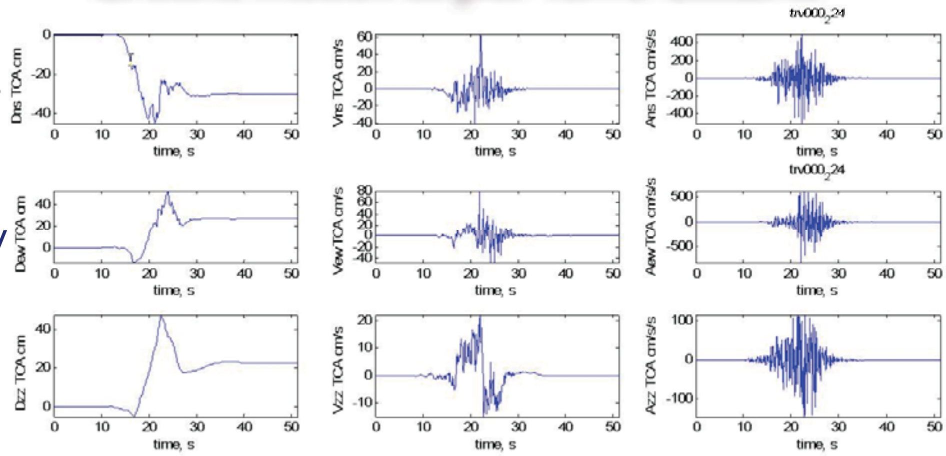
NS / EW / Z



a) variant 222

Ground motion at pier Torre Calabria

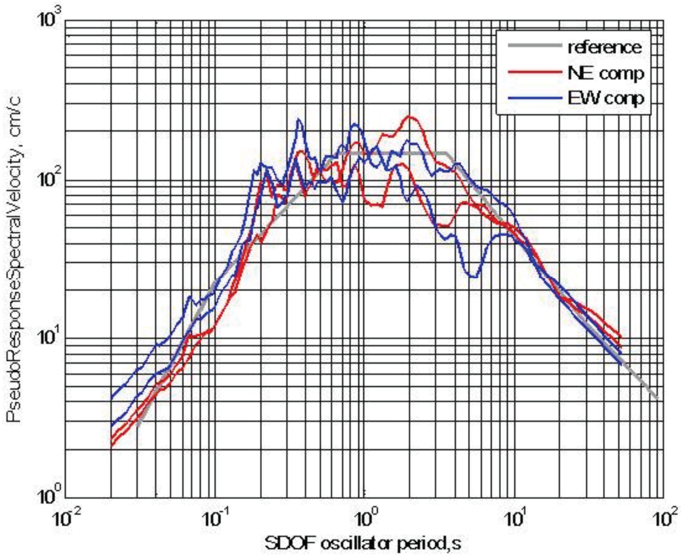
NS / EW / Z



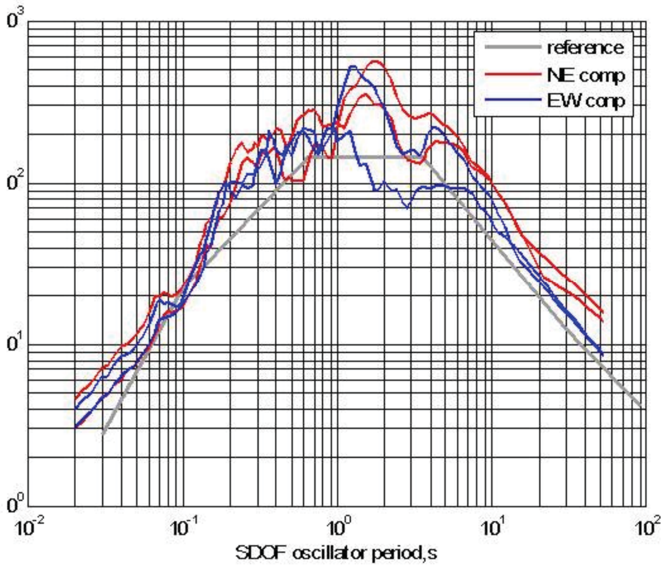
b) variant 224

PRV

Variant 222

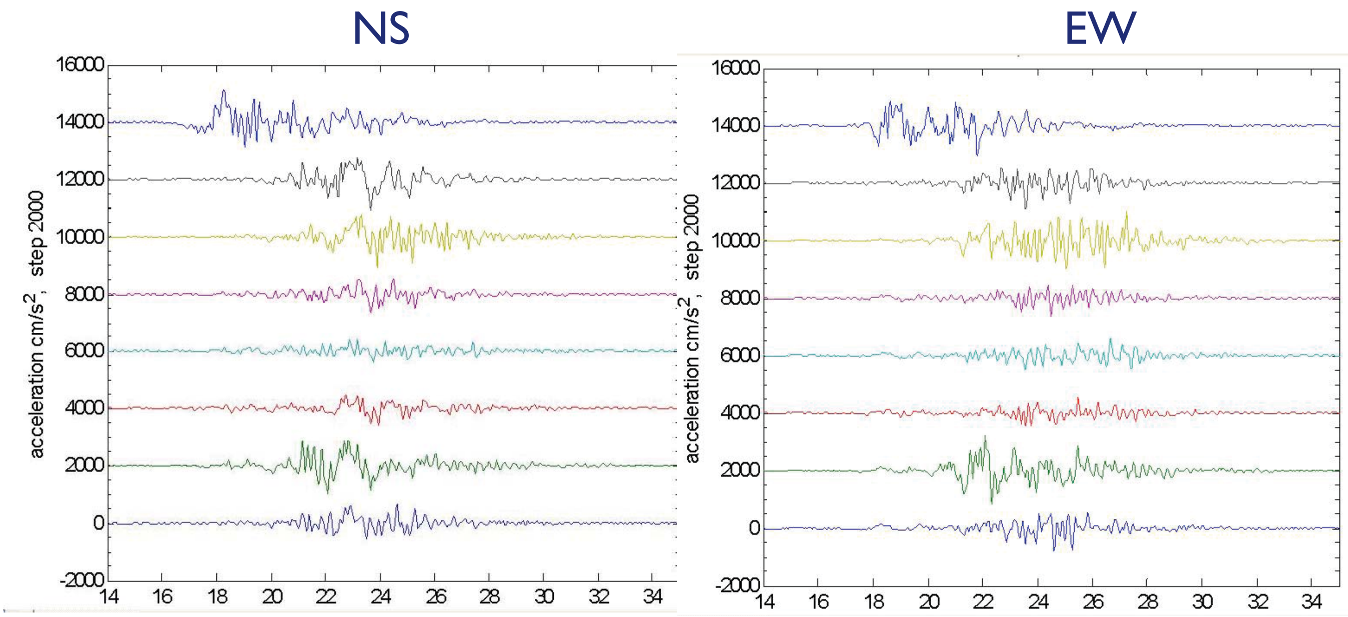


Variant 224



PRV (response velocity spectra) for horizontal components, both piers on one plot. Variant 224 exceeds significantly the reference spectrum (SM-PRV), proposed by Stretto di Messina (2004).

Variability respect to rupture history



Examples of the considerable variability of the accelerograms in the individual simulations. Eight sample functions of the ground acceleration at Torre Sicilia for the horizontal components. Vertical interval between zero-lines of traces is 2000 cm/s^2 . The first trace is for the less usual source sample function, when a large asperity happened to coincide with the spot with the highest permitted propagation velocity

Considerations...

We compare a set of response horizontal velocity spectra (PRV) obtained from our calculations with a reference PRV that is considered as a reasonable upper bound for the possible ground motion near the piers. Our results suggest that the seismic ground motion under Torre Sicilia dominates that under Torre Calabria and that the median PRV is generally above the reference one, about 1.1-1.3 times for T>4 s, and up to 2 times for 1<T≤4 s.

The use of advanced fault and medium models, accounting also for the natural scatter of individual PRV spectra due to events with the same gross source parameters, provides a sound basis for the deterministic engineering estimates of future earthquake ground motion.

Road map

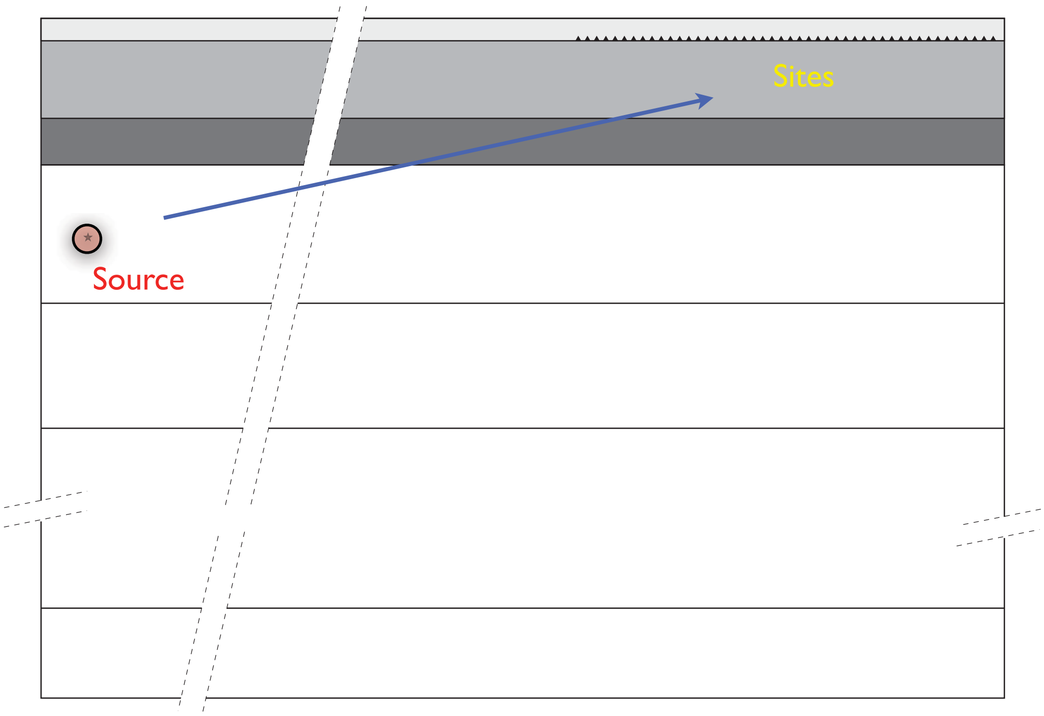
- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology (Site effects)

Introduction - Local scale

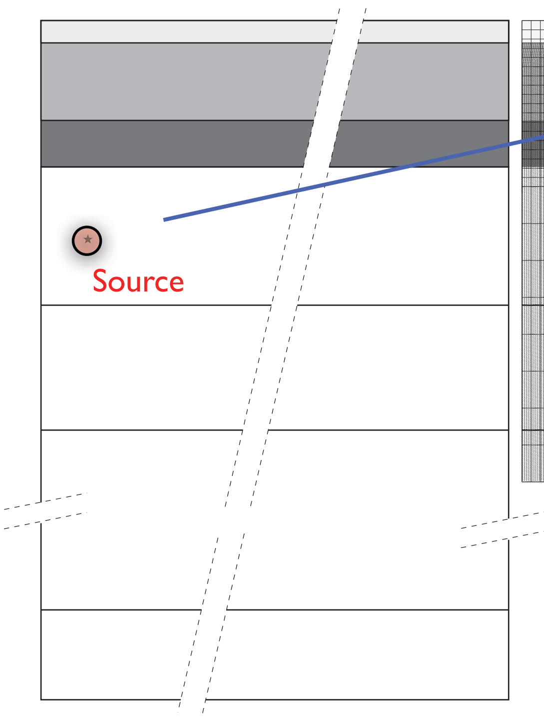
- Synthetic seismograms along selected profiles
- Laterally heterogenous structural models
- Detailed source models
- Cutoff frequency up to 10 Hz
- Time series, amplification maps

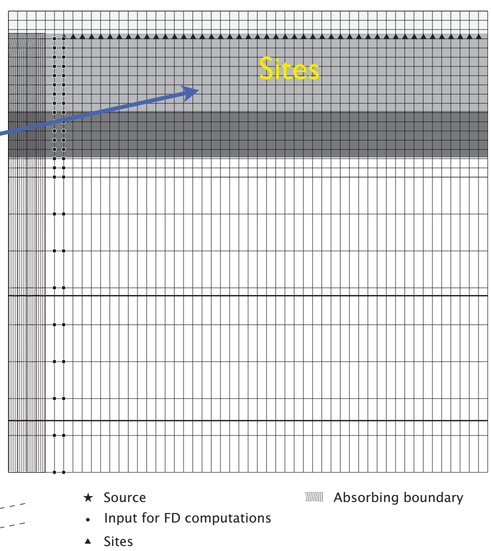
Methodology - Modal summation (regional scale)

Modal summation



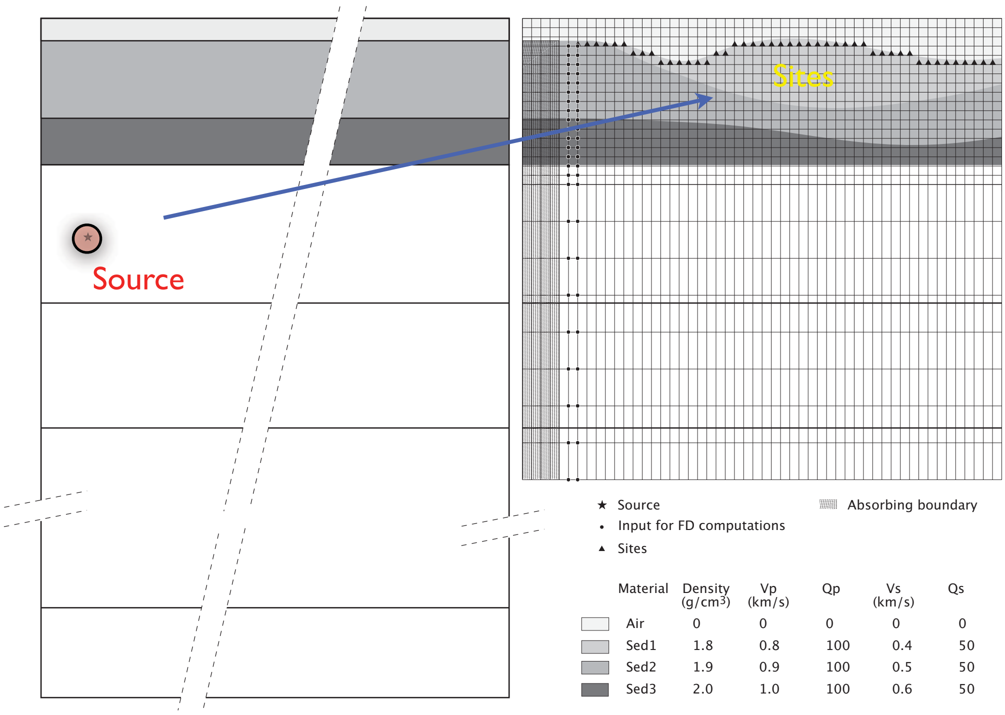
Methodology - Hybrid technique (local scale)





Material	Density (g/cm3)	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



Material	Density (g/cm³)	Vp (km/s)	Qp	Vs (km/s)	Qs
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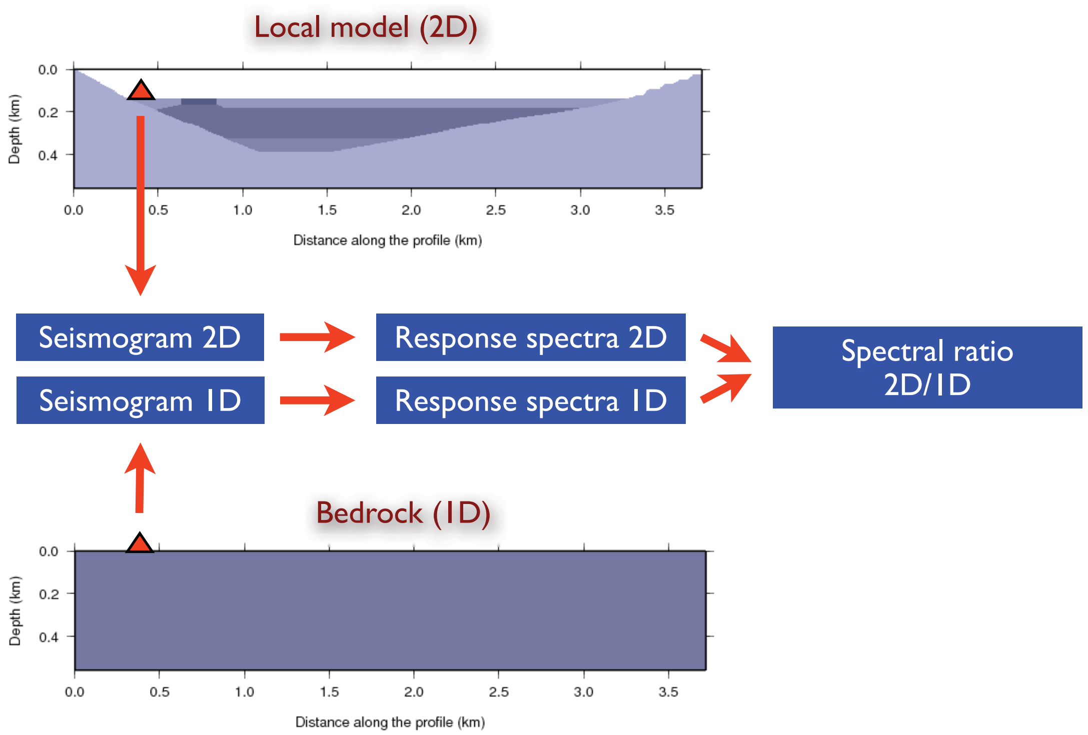
Sed1	1.8	0.8	100	0.4	50
Sed2	1.9	0.9	100	0.5	50
Sed3	2.0	1.0	100	0.6	50

Methodology- 2D/1D spectral amplifications



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- Groundshaking scenarios modelling
  - Methodology
- Groundshaking scenarios modelling
  - Application to critical facility (real bridges...)

Romanelli F., Panza G.F. ,Vaccari, F., 2004.
Realistic Modelling of the Effects of Asynchronous motion at the Base of Bridge Piers, Journal of Seismology and Earthquake Engineering, Vol. 6, No. 2, pp. 19-28

VAB Project (EC)

ADVANCED METHODS FOR ASSESSING THE SEISMIC VULNERABILITY OF EXISTING MOTORWAY BRIDGES

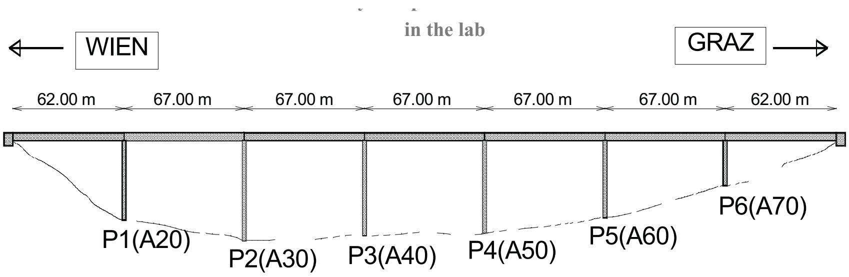
ARSENAL RESEARCH, Vienna, Austria; ISMES S.P.A,. Bergamo, Italy; ICTP, Trieste, Italy; UPORTO, Porto, Portugal; CIMNE, Barcelona, Spain; SETRA, Bagneaux, France; JRC-ISPRA, EU.

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

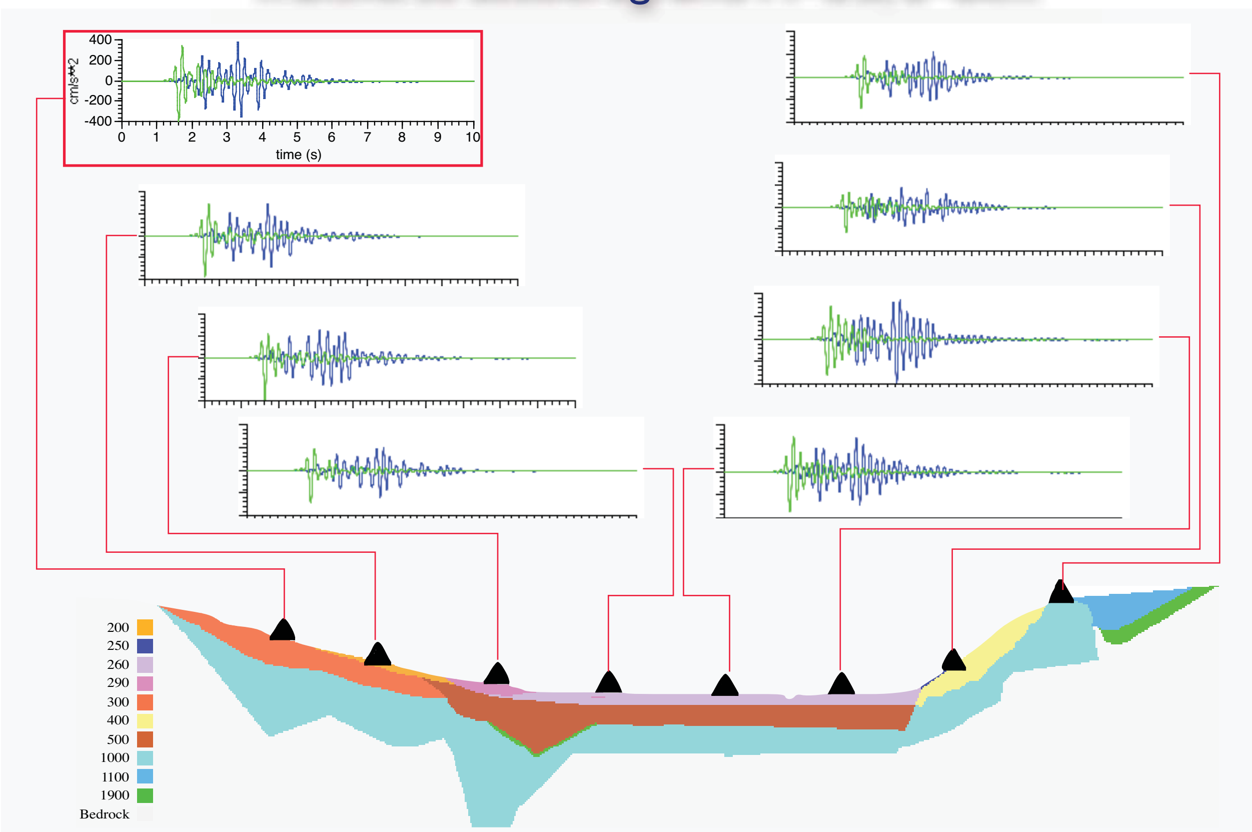
Warth bridge

The bridge was designed for a horizontal acceleration of 0,04 g using the quasi static method.

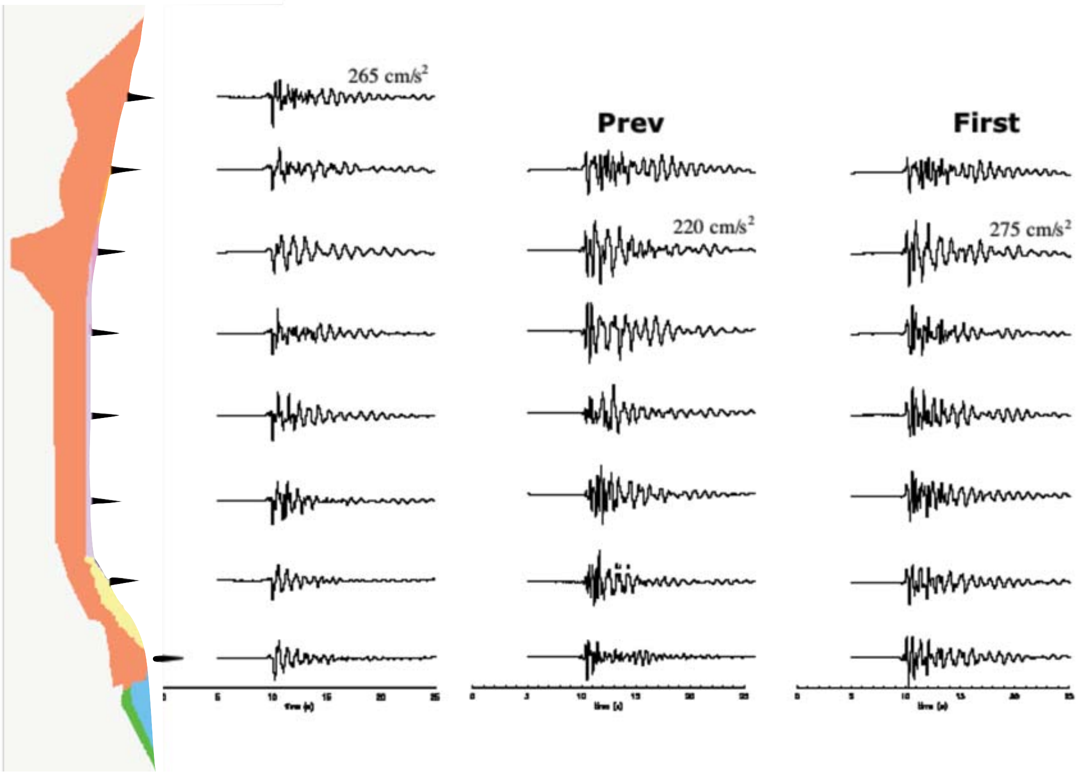
According to the new Austrian seismic code the bridge is situated in zone 4 with a horizontal design acceleration of about 0,1 g: a detailed seismic vulnerability assessment was necessary.



Transverse accelerograms M=5.5, d=6km



Synthetic accelerations and diffograms



Implementation of PSD tests

Joint Research Centre

PSD WITH SUBSTRUCTURING

Application to the Warth Bridge, Austria

Construction of the large-scale bridge piers outside of the ELSA lab

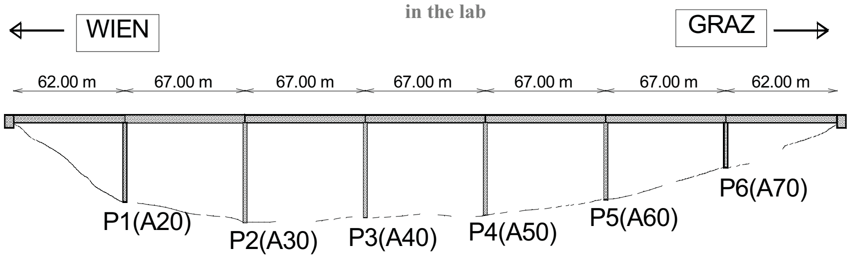
Physical piers A40 & A70 in the lab

Numerical models for the substructured piers A20, A30

Numerical models for the substructured piers A50, A60

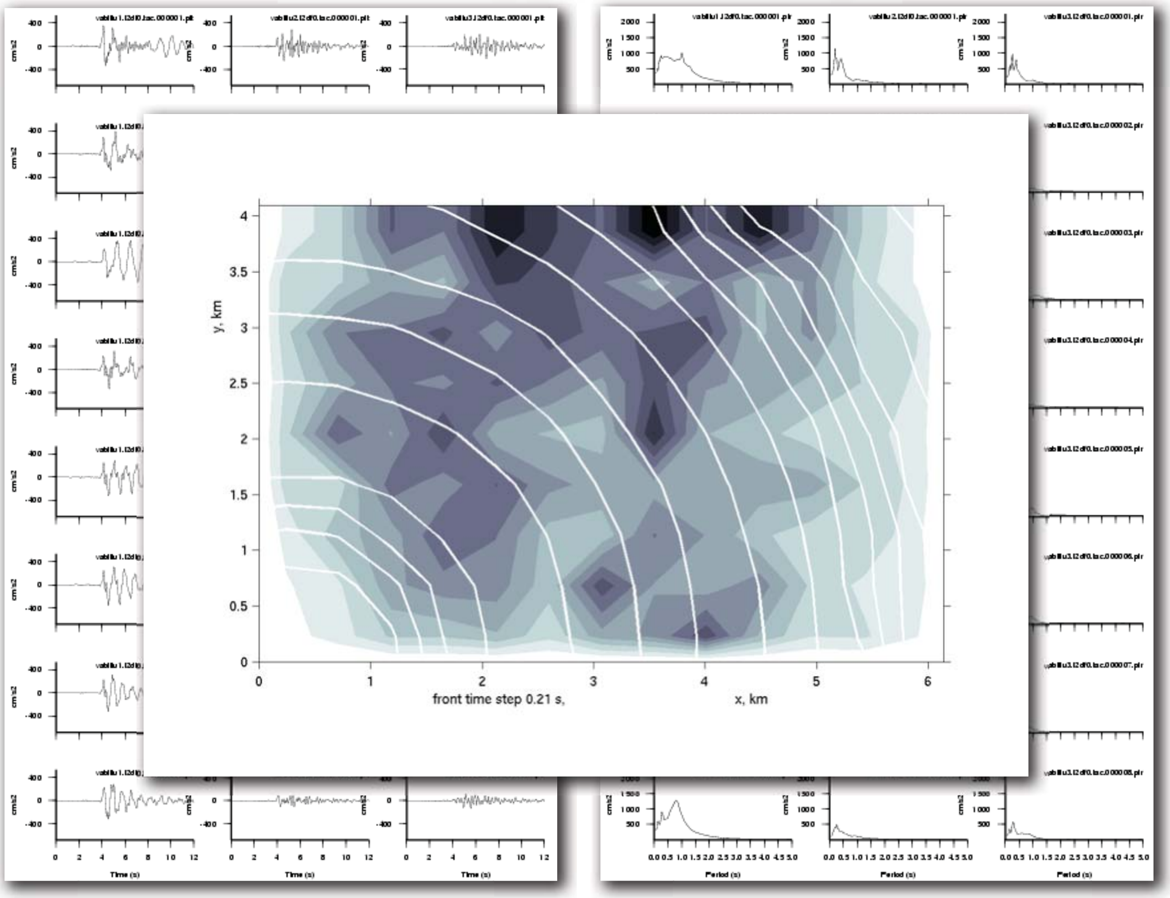
Numerical model for the deck and PSD master

Master experimental process

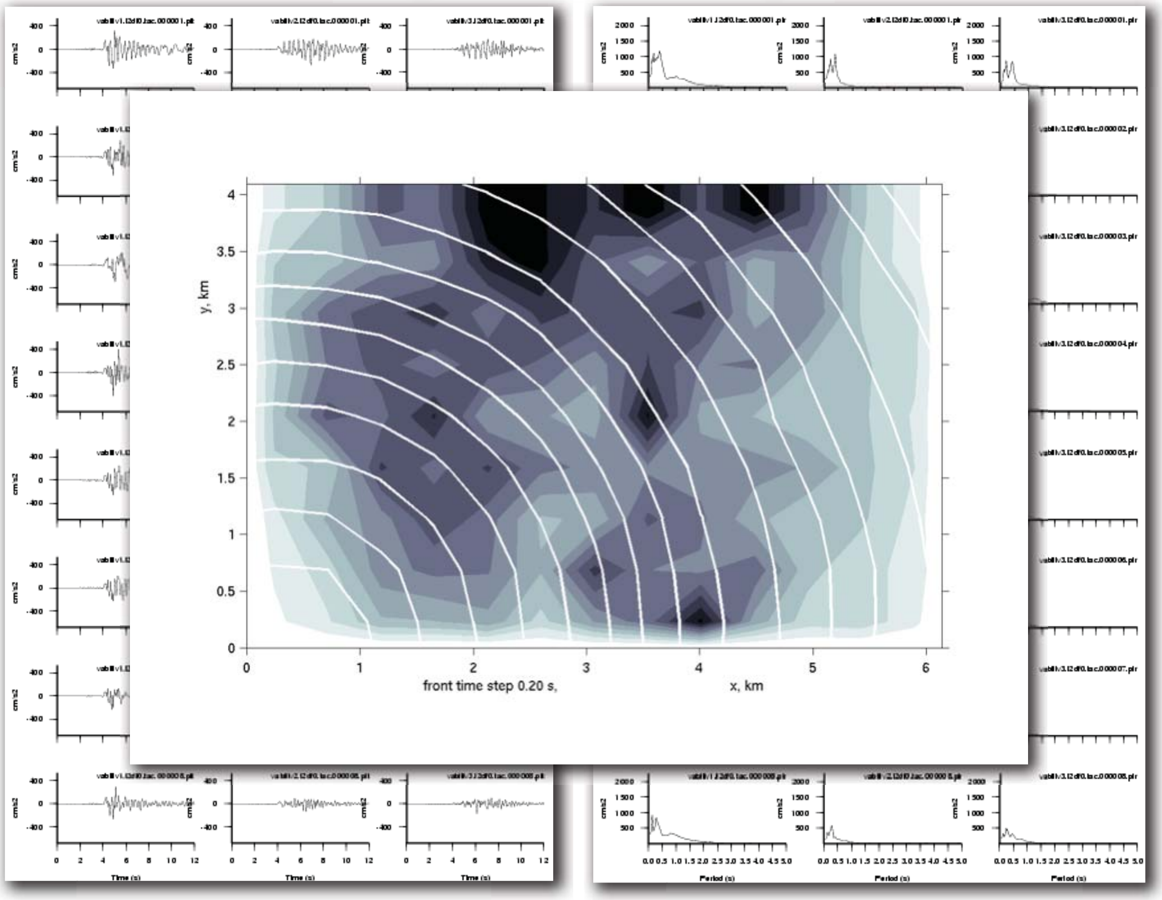


Warth Bridge

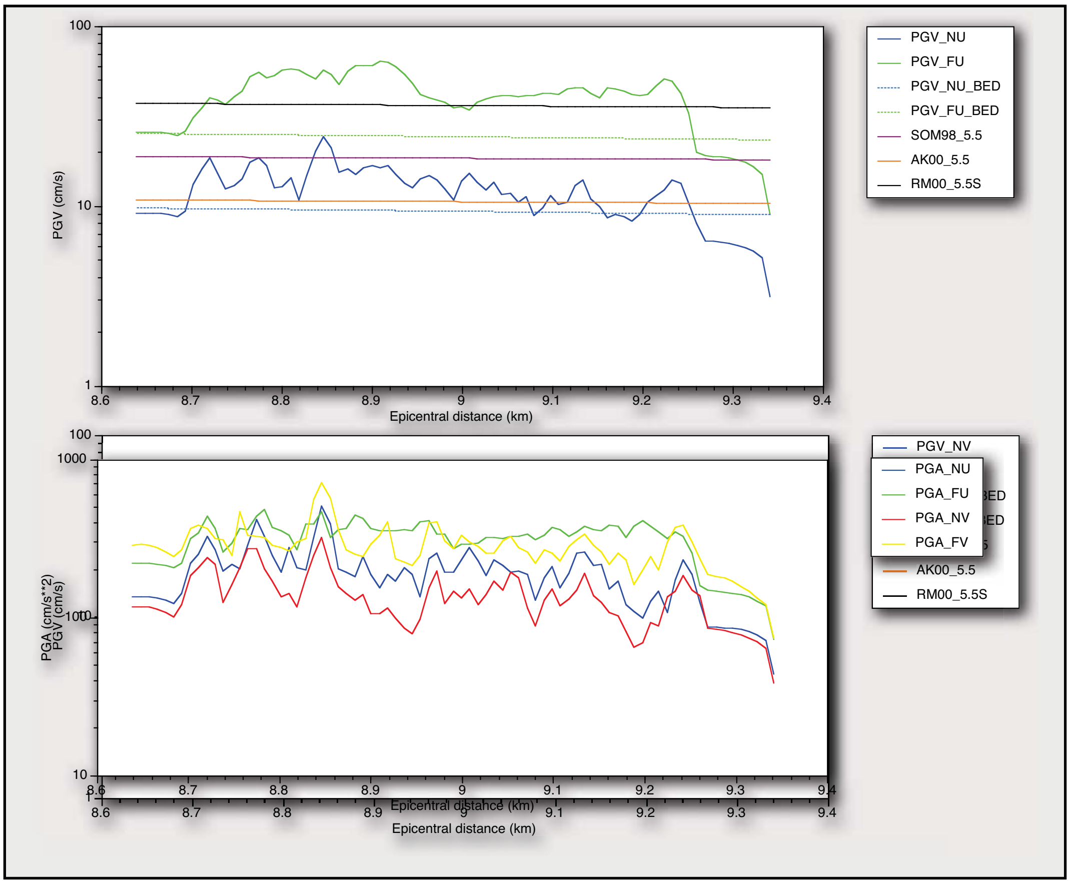
Directivity parametric study



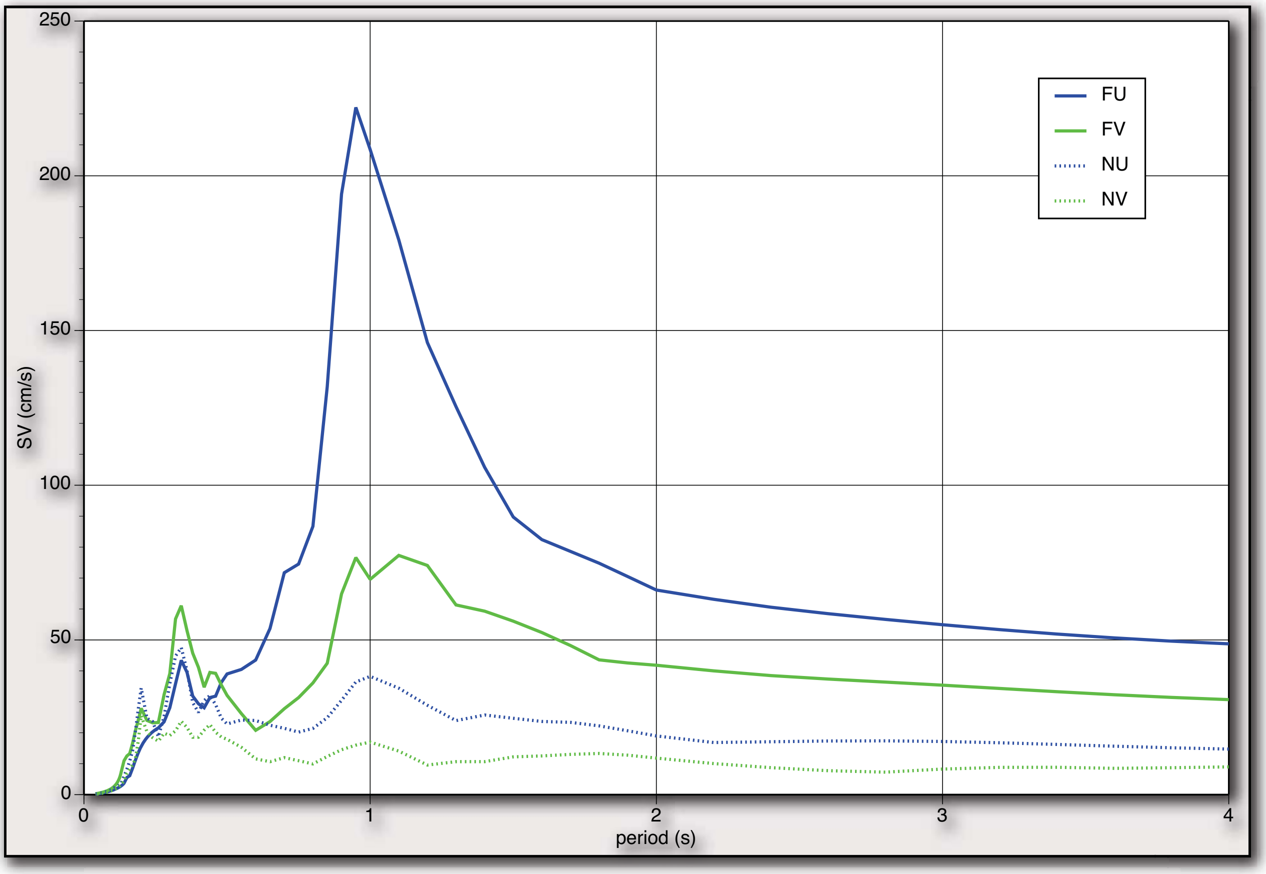
ESp towards directivity



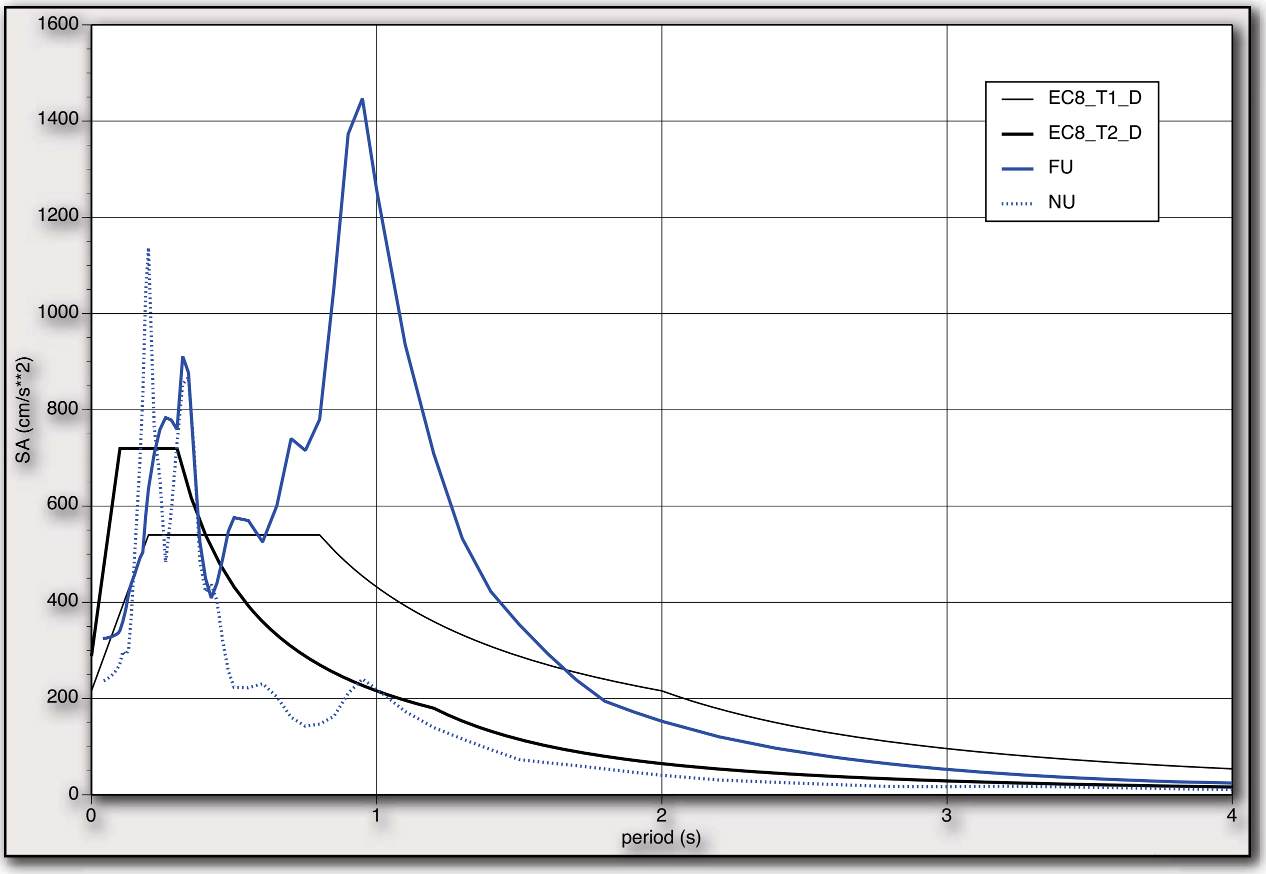
Directivity & PGV - PGA



Directivity & SV



Directivity & SA



Road map

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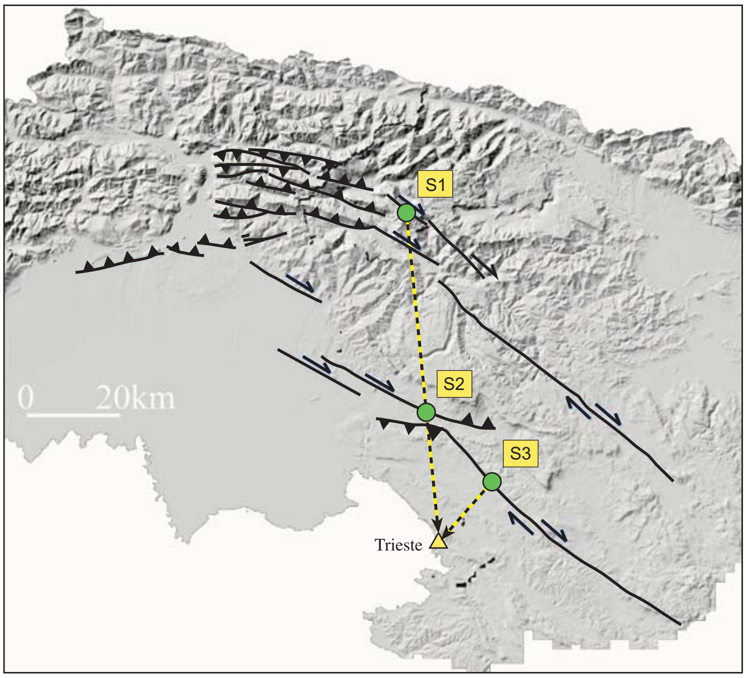
  - Methodology
- Groundshaking scenarios modelling
  - Application to Triest

Vaccari F., Romanelli F., Panza G. F. (2005).
Detailed modelling of strong ground motion in Trieste; Modellazione dettagliata del moto sismico del suolo a Trieste". *Geologia tecnica e ambientale*, Vol. 2, pp. 7-40.

Local Scale - Choice of Scenario Earthquakes

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

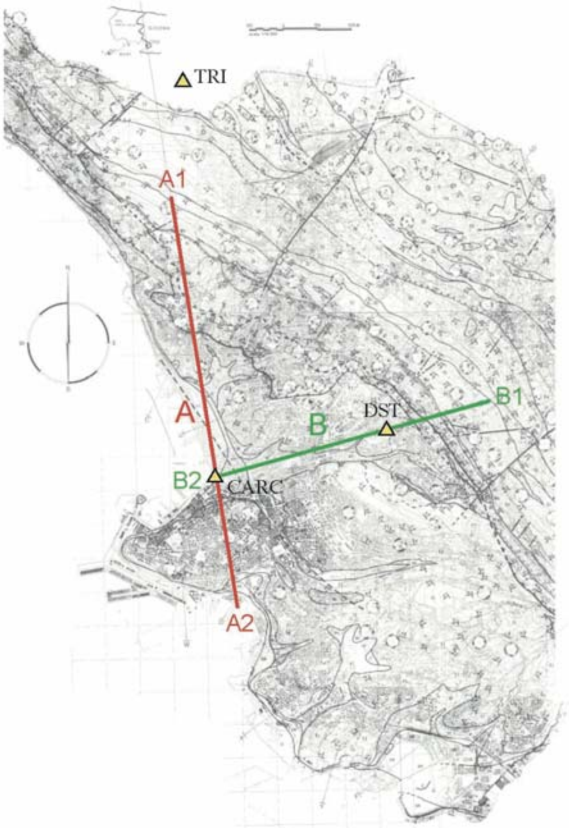


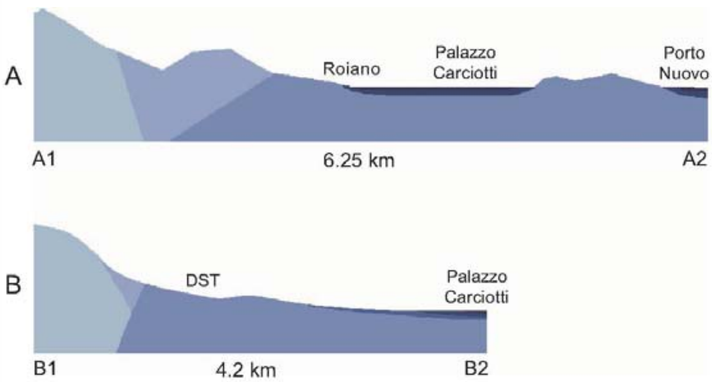
S1 in the Bovec zone
(65 km from Trieste)

S2 East of Gorizia
(30 km from Trieste)

S3 at 17 km from Trieste

Local Scale - Choice of Profiles

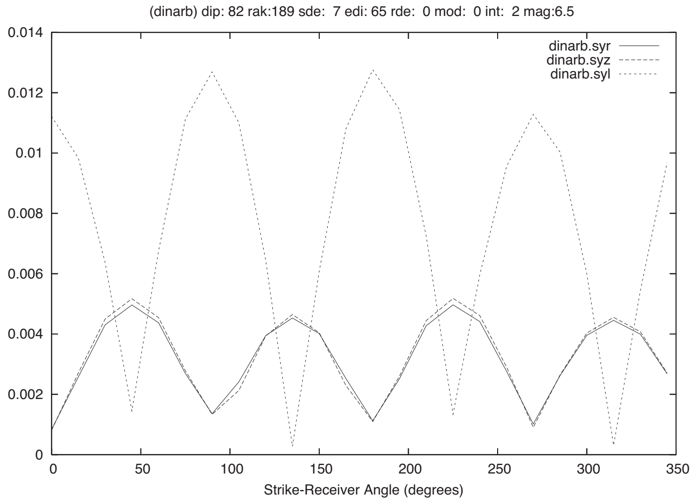




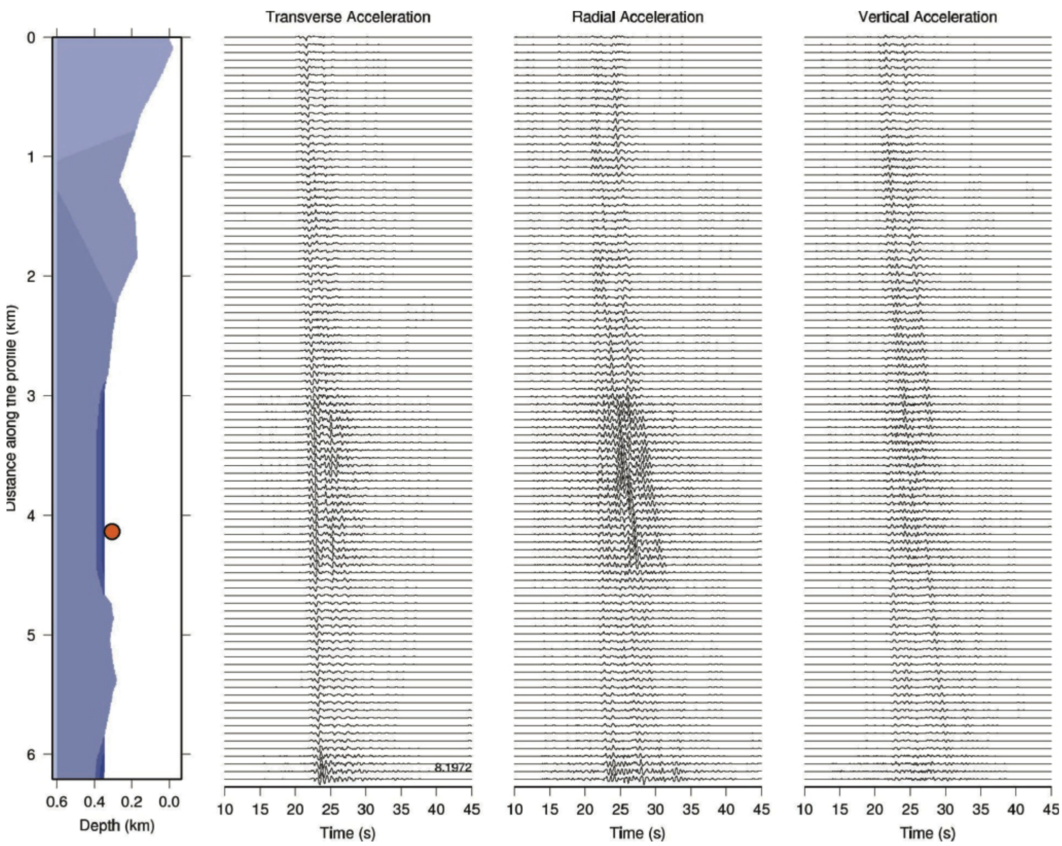
Litotipo	Densità (g/cm^3)	Vp (km/s)	Vs (km/s)	Qp	Qs
Riporti	1.8	0.4	0.2	30	15
Sed. Marini	1.9	0.8	0.4	40	20
Alluvioni	1.95	1.0	0.5	40	20
Flysch	2.0	1.8	1.0	100	50
Marne	2.0	1.9	1.1	200	100
Arenarie	2.1	2.0	1.2	200	100
Calcari	2.3	2.5	1.4	200	100

Local Scale - Preliminary Parametric Test

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

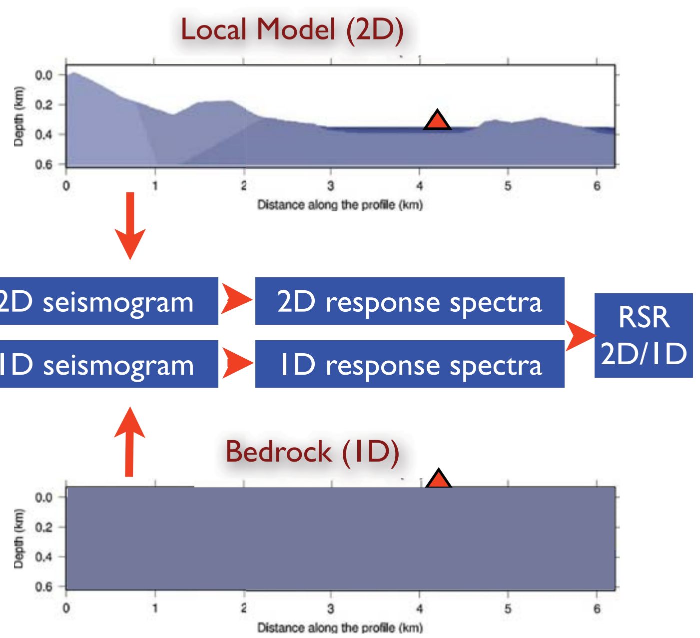


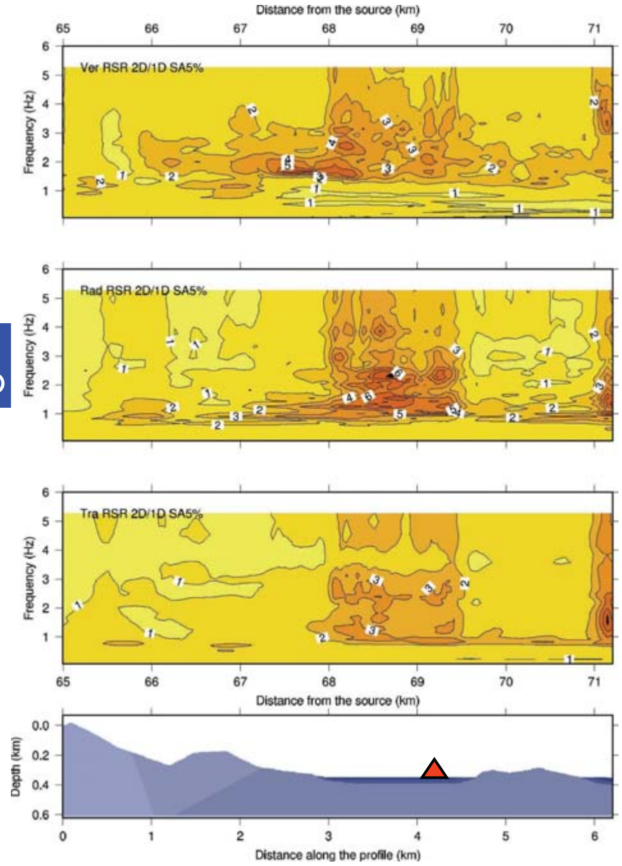
Local Scale - Synthetic Seismograms



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

Local Scale - Response Spectra Ratio

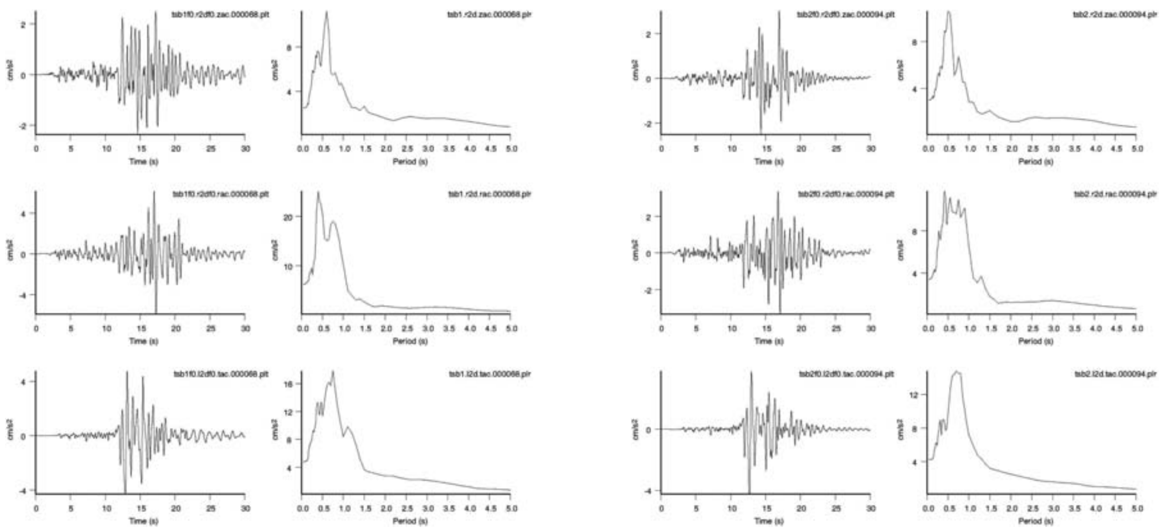




Site effects in Trieste city centre may cause a significant amplification (up to 5 times at engineering relevant frequencies) of the seismic signal at bedrock, hence intensity may reach IX (MCS) or VIII (MSK).

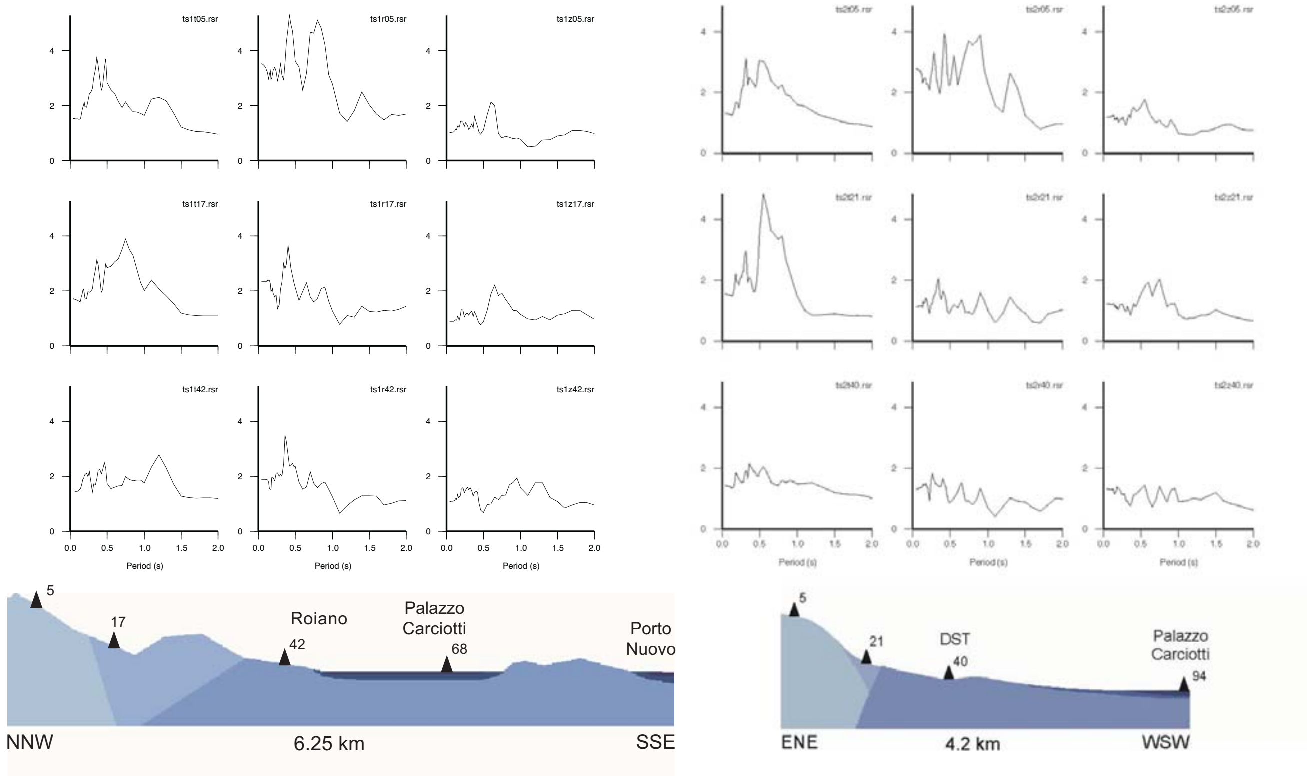
Local Scale - Response Spectra

- Same site at the intersection of two profiles



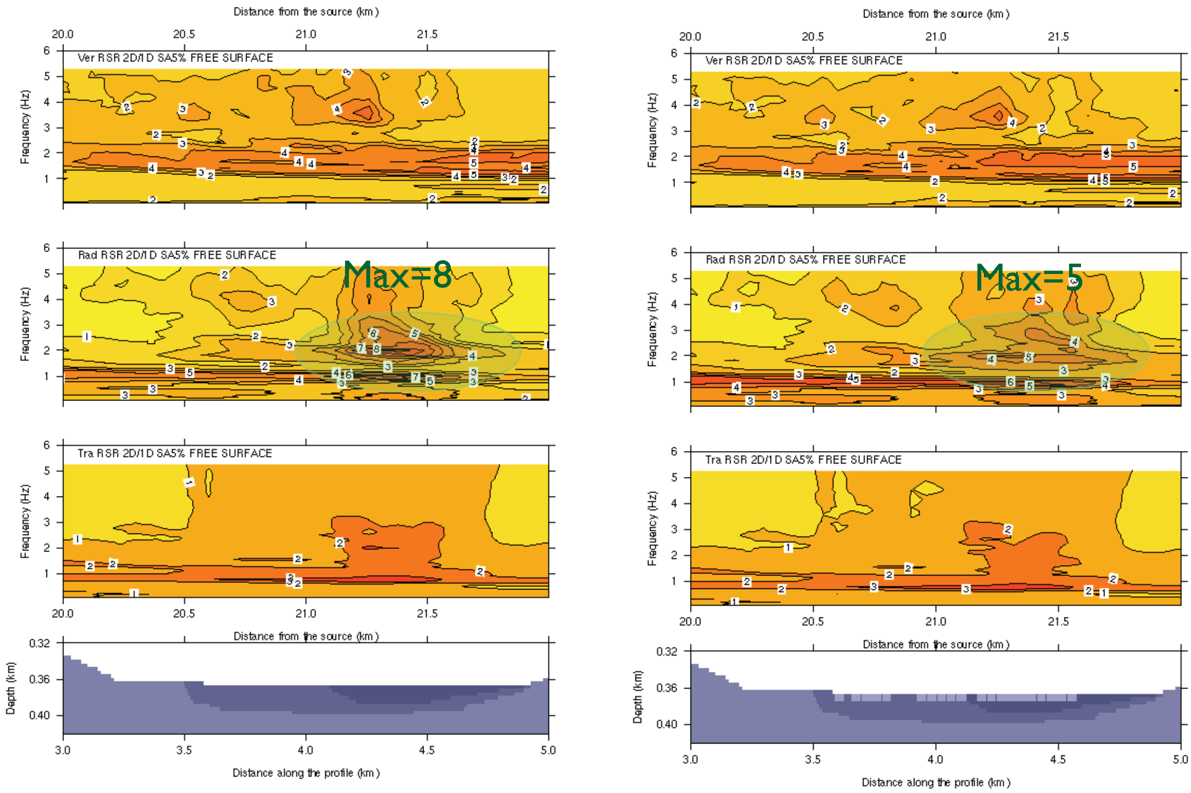
Local Scale - Response Spectra Ratio

Choice of reference site



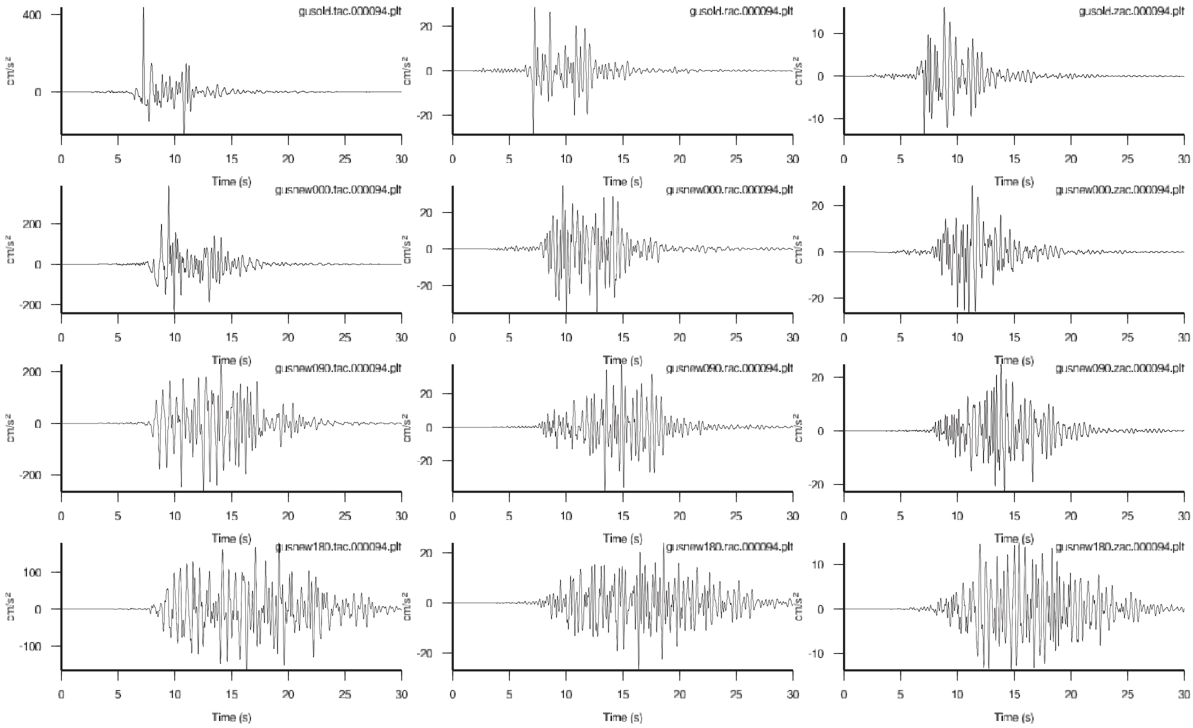
Local Scale - RSR with Soil Interaction

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



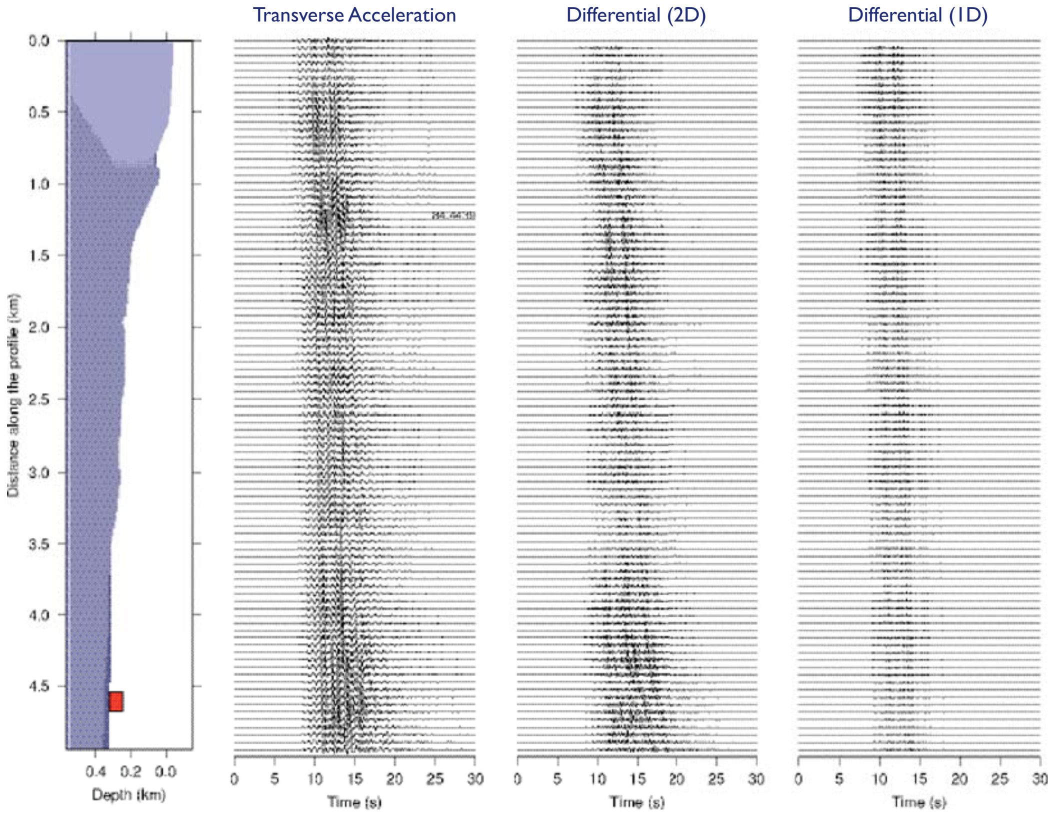
Local Scale - Source Model

- Seismic Source of finite dimension and complicated rupturing process



Local Scale - Differential Motion

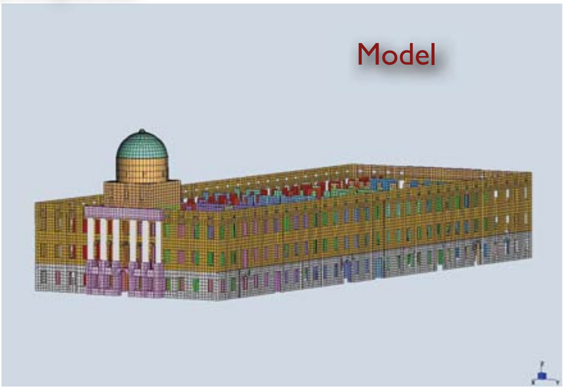
- Significant for elongated structures (bridges, lifelines etc)

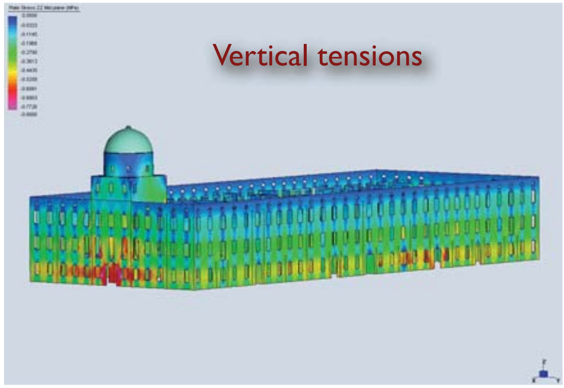


Engineering analysis - Triest case

- 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





Road map

- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology
- Groundshaking scenarios modelling
  - Application to Valparaiso

http://www.marvasto.bologna.enea.it/

“MAR VASTO” - Manejo de riesgos en Valparaiso

CONTRACT BID-ENEA n. ATN/II-9816-CH

PARTNERSHIP

ENEA, Ente per le Nuove tecnologie, l’Energia e l’Ambiente

UNIFE, Università di Ferrara, Dip. di Architettura e Ingegneria

ICTP, Abdus Salam International Centre for Theoretical Physics, Trieste

UNIPD, Università di Padova, Facoltà di Ingegneria, Dipartimento di Costruzioni e Trasporti

USM, Universidad Tecnica Federico Santa Maria, Departamento de Obras Civiles

UC, Universidad de Chile, División Estructuras Construcción Geotecnia, Departamento de Ingeniería Civil, Facultad de Ciencias Físicas y Matemáticas

PARTNERSHIP

OGP, Ilustre Municipalidad de Valparaíso, Oficina de Gestion Patrimonial

VALPOMIO, Programa de Recuperación y Desarrollo Urbano de Valparaíso

“MAR VASTO” - “Manejo de riesgos en Valparaiso”

Patrimonio Cultural de la

“MAR VASTO” - “Manejo de riesgos en Valparaiso”

DISASTER HAZARD MAPS
(earthquakes, tsunami, landslides, fires)

SURVEYS
(photos, GPS, geology, laser scanner 3D)

VULNERABILITY ANALYSIS
(synthetic sheets, structural calculations)

GIS
(geo-referenced database for risk management)

MULTIMEDIA ACTIVITIES
(movies, workshops, publications)

FINAL PROPOSALS
(guidelines for future interventions)

INVESTIGATION ON THREE HISTORICAL CHURCHES
(San Francisco, La Matriz, Las Hermanas de La Providencia)

INVESTIGATION ON A PILOT BUILDING STOCK
(Cerro Cordillera)

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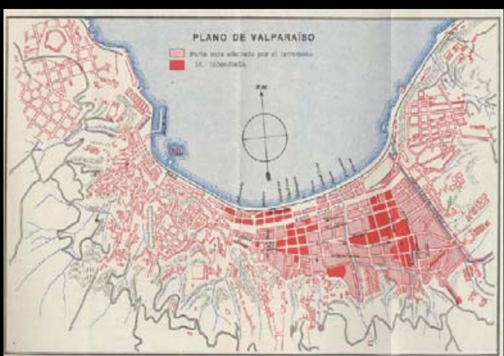
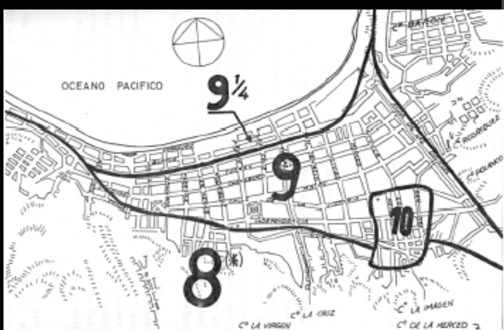
SEISMIC HAZARD





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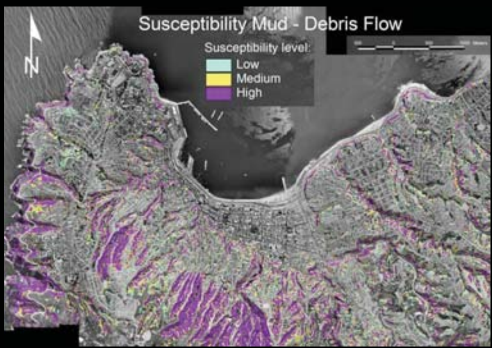
LANDSLIDE HAZARD

Cooperation with UC,
USM, OGP
cartography
quebradas Cerro Cordillera



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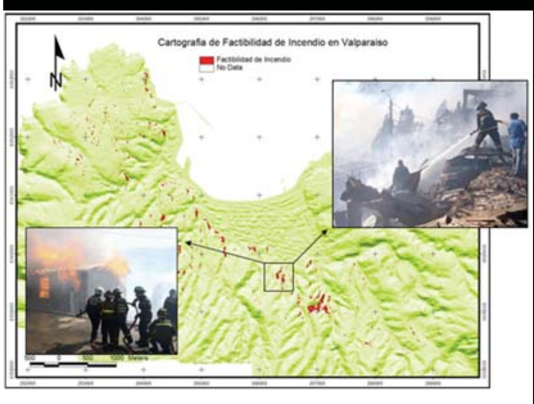
FIRE HAZARD

Cooperation with UC,
USM, OGP,OREMI, CORPO
DEI POMPIERI
cartography
churches protection
pilot study Cerro
Cordillera



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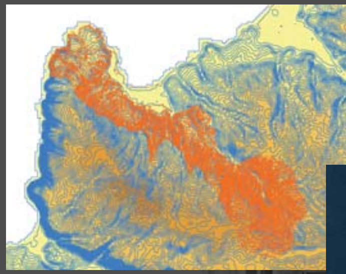
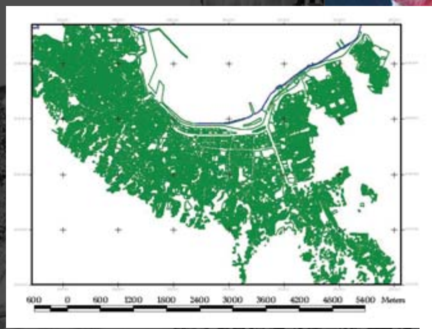
GIS DATABASE

cooperation with
OGP,OREMI, SHOA,
FIREMEN CORP
cartography
aerial photos
vulnerability analysis





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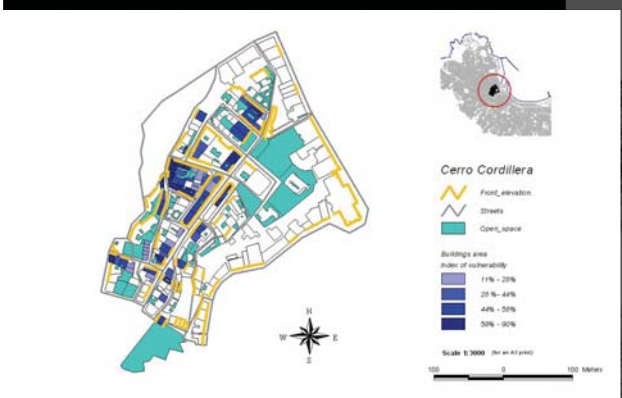
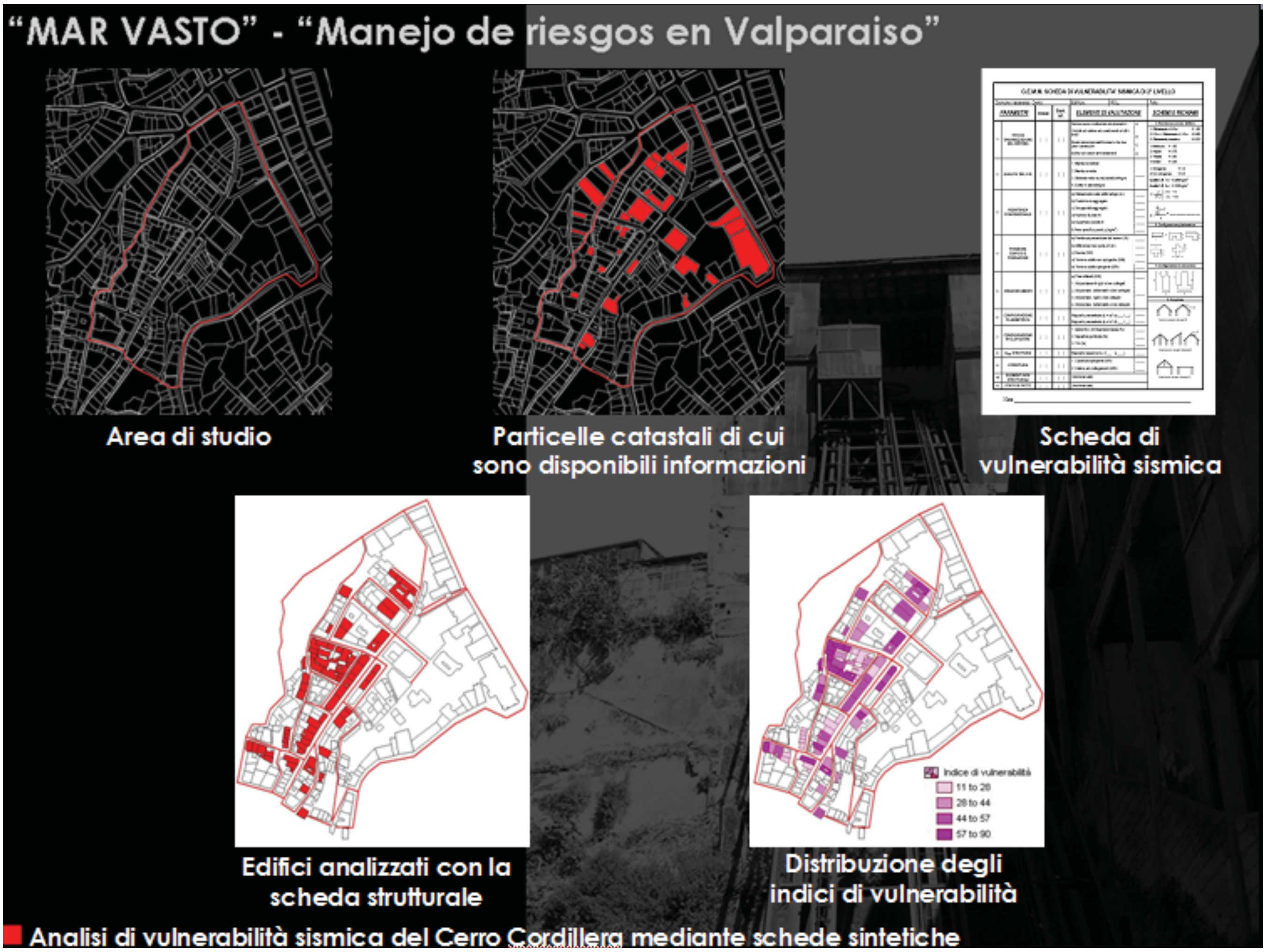
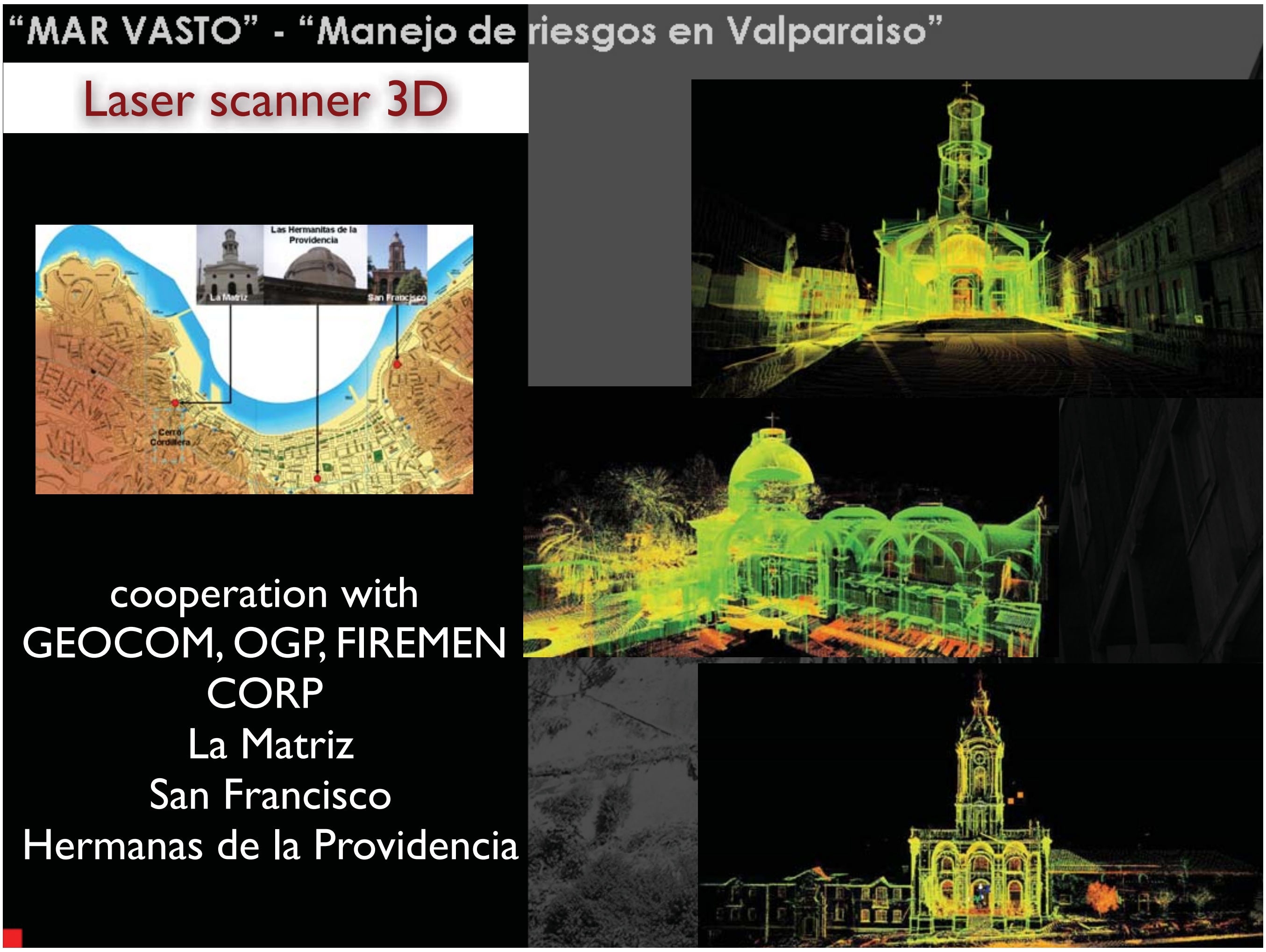
Urban planning analysis
Cerro Cordillera pilot area

In situ vulnerability
investigation
restoration proposals




"MAR VASTO" - "Manejo de riesgos en Valparaiso"
Area di studio
Particelle catastali di cui sono disponibili informazioni
Scheda di vulnerabilità sismica
Edifici analizzati con la scheda strutturale
Indice di vulnerabilità
11 to 28
28 to 44
44 to 57
57 to 90
Distribuzione degli indici di vulnerabilità
Analisi di vulnerabilità sismica del Cerro Cordillera mediante schede sintetiche


"MAR VASTO" - "Manejo de riesgos en Valparaiso"
Laser scanner 3D
Las Hermanitas de la Providencia
La Matriz
San Francisco
Cerro Cordillera
cooperation with
GEOCOM, OGP, FIREMEN CORP
La Matriz
San Francisco
Hermanas de la Providencia

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IGLESIA SAN FRANCISCO DEL BARON

La chiesa necessita di un restauro sulla torre campanaria per il consolidamento statico e dinamico possibile con interventi poco invasivi.

IGLESIA DEL SALVADOR, MATRIZ DE VALPARAISO

La chiesa risulta in buone condizioni statiche con la necessità, però, di un'intervento di recupero per il degrado dei materiali e di prevenzione per l'incendio.

CAPILLA DE LA PROVIDENCIA

La chiesa necessita di un restauro diffuso su tutta la chiesa per il consolidamento statico e dinamico.

PRIME CONSIDERAZIONI SULLA VULNERABILITà SISMICA DELLE TRE CHIESE

"MAR VASTO" - "Manejo de riesgos en Valparaiso"

SEISMIC HAZARD

Objectives:

- Hazard at a regional scale
- Scenario parametric tests

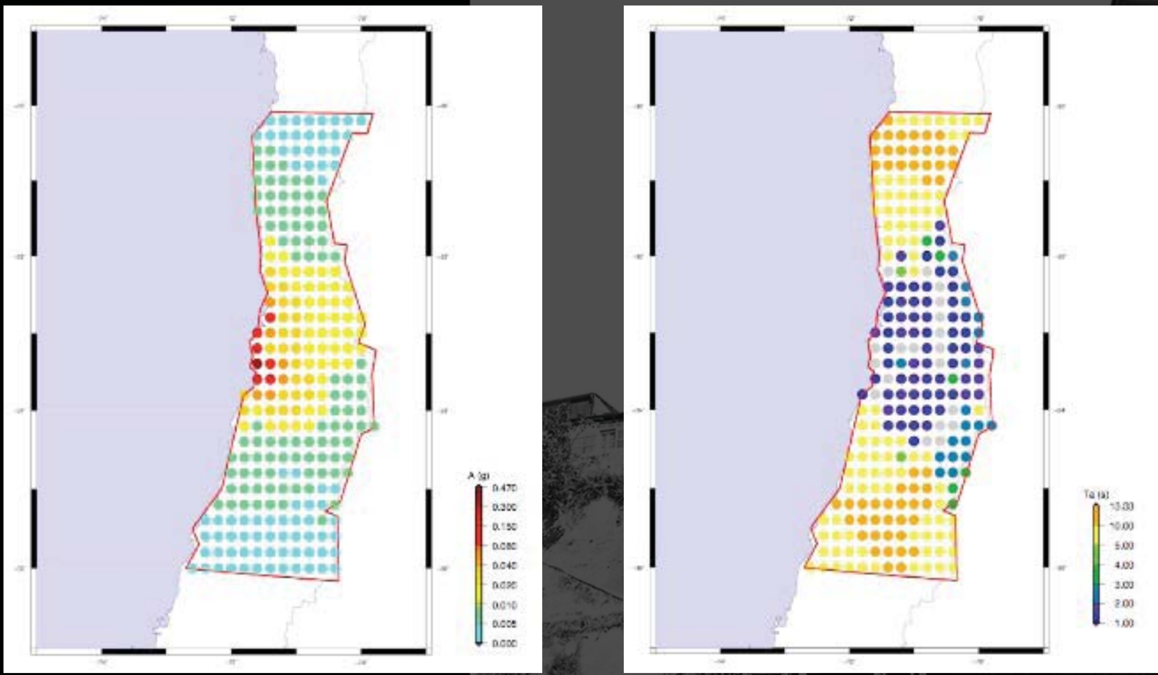
  Validation with experimental data
- Seismic input at urban scale

  3 selected churches

  Selected profiles with site effects

SEISMIC HAZARD

Regional scale



Horizontal PGA distribution and Period in seconds of its maximum after hazard deaggregation of the 1906 and 1985 events

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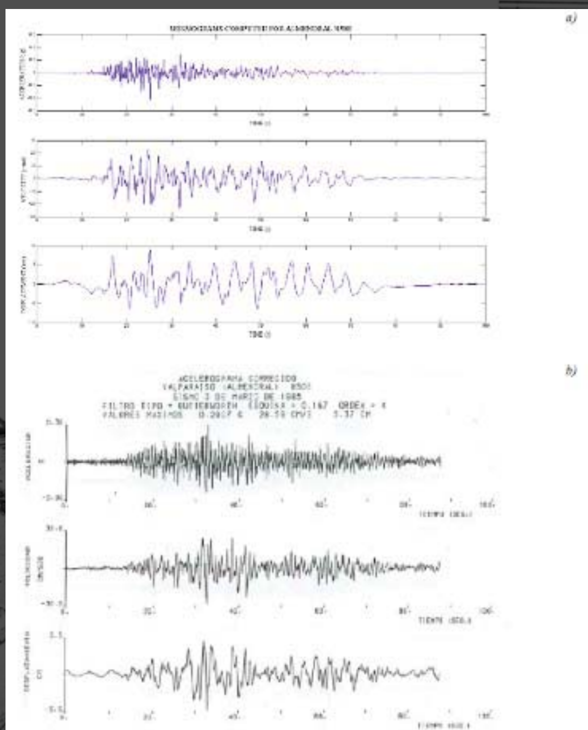
SEISMIC HAZARD

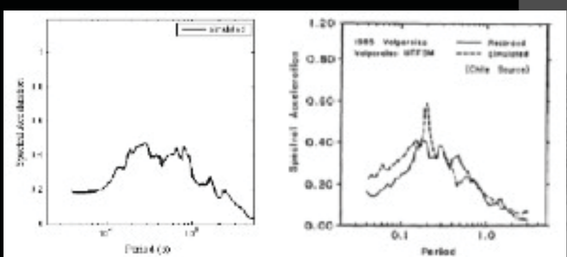
Validation

El Almendral station: acceleration, velocity and displacement for the 1985 event.

a) computed (unilateral rupture)

b) recorded.





Comparison of response spectra: this study, recorded and the one simulated by Somerville et al., 1991.

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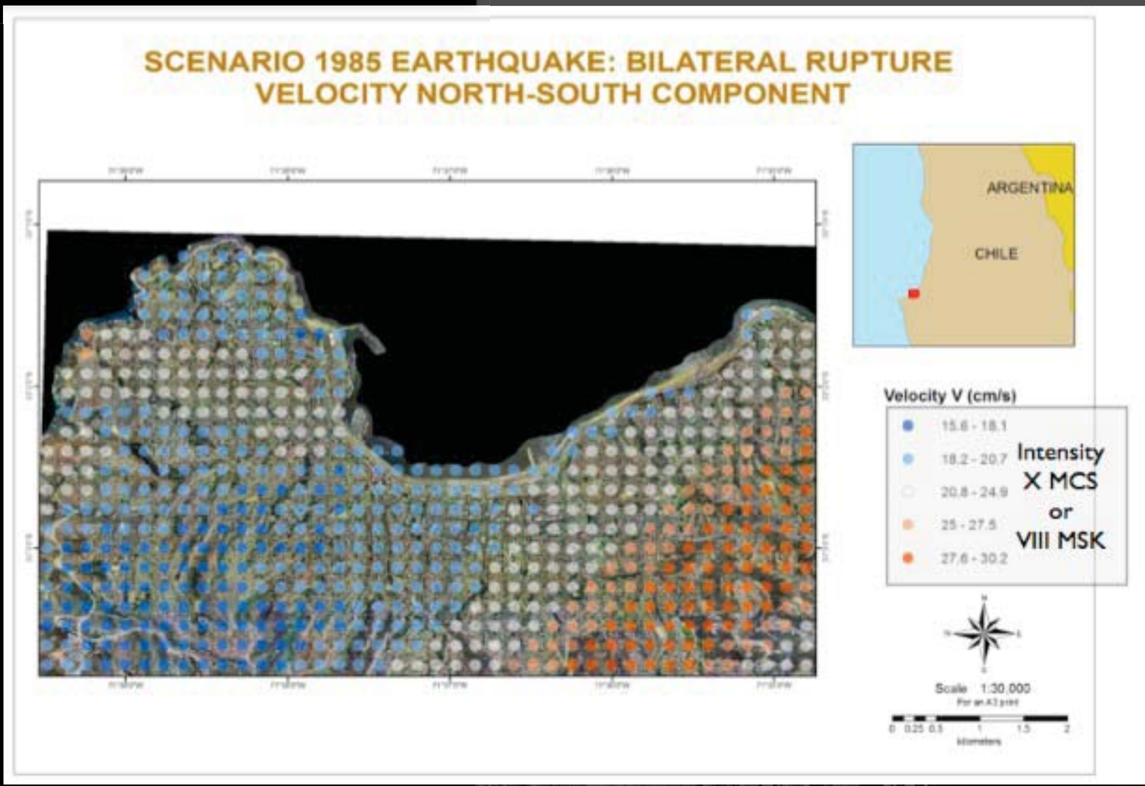
SEISMIC HAZARD

Urban scale



Groundshaking scenario in the Valparaiso urban area for the 1985 event.
NS component of velocities for bilateral rupture.

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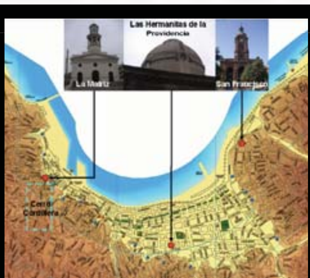
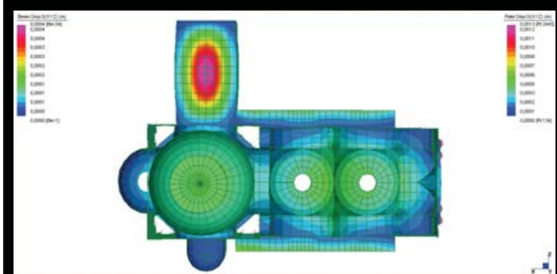
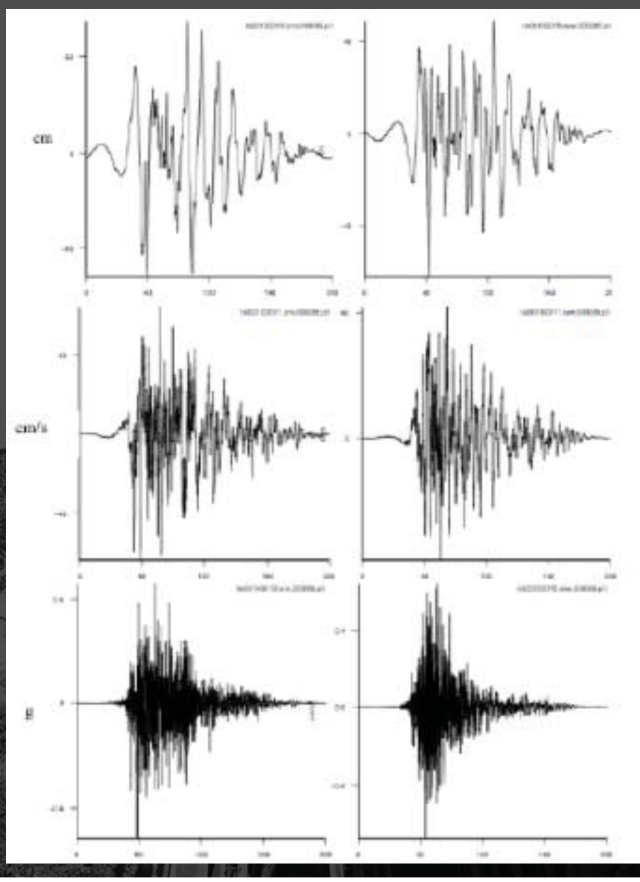
SEISMIC HAZARD

Seismic input for 3 selected churches





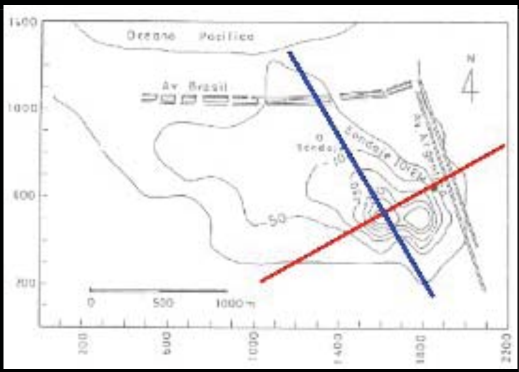


Example of seismic input computed at the La Matriz church: 1906 scenario, bilateral rupture.

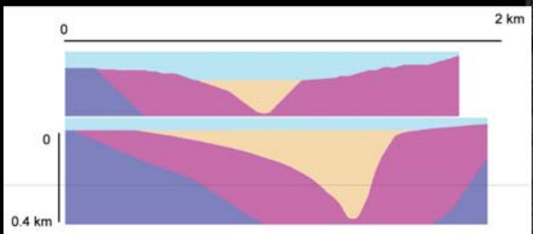
Displacements, velocities and accelerations for the two horizontal components of motion.

SEISMIC HAZARD

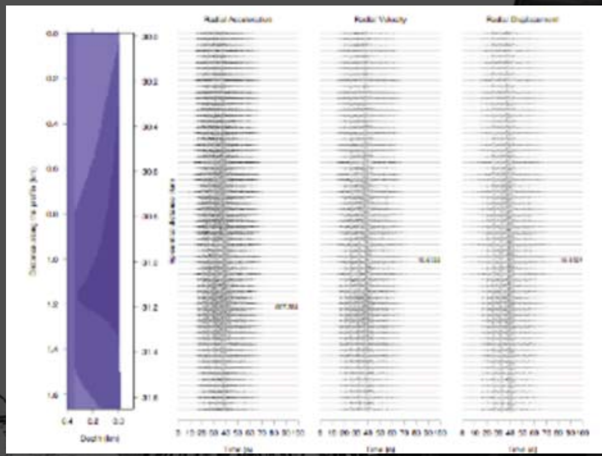
Profiles & site effects



Bedrock model (depth) at El Almendral and the position of the two profiles with their parameters.



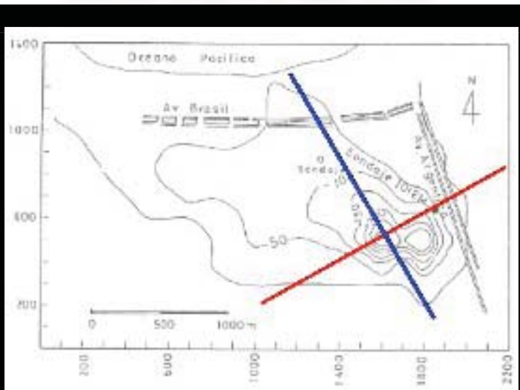
	Density (g/cm³)	Vp (km/s)	Vs (km/s)	Qp	Qs
Air					
Sed.1	1.5	1.365	0.665	80	40
Sed. 2	1.6	2.400	1.300	110	50
Bedrock	1.7	4.500	2.500	110	50

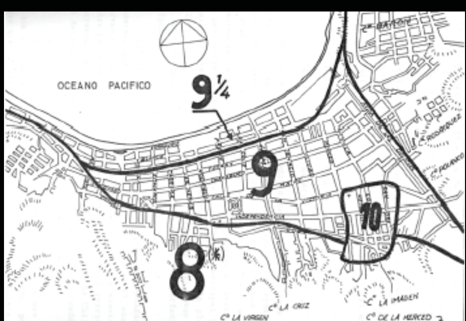


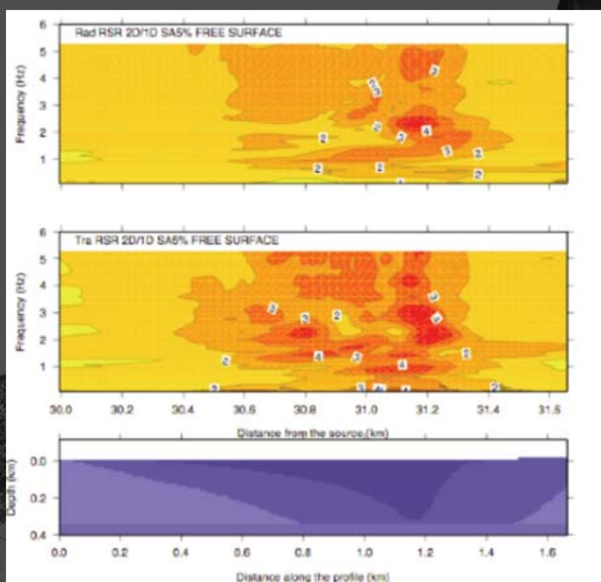
Radial component of motion along profile 2.
1906 scenario

SEISMIC HAZARD

Regional scale







Spectral amplifications obtained along profile 2.
From top to bottom: radial and transverse component.

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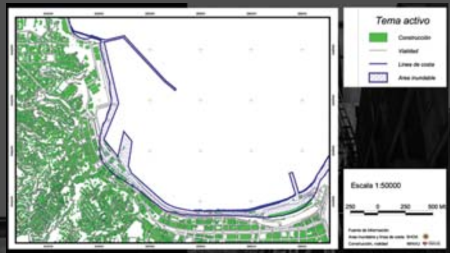
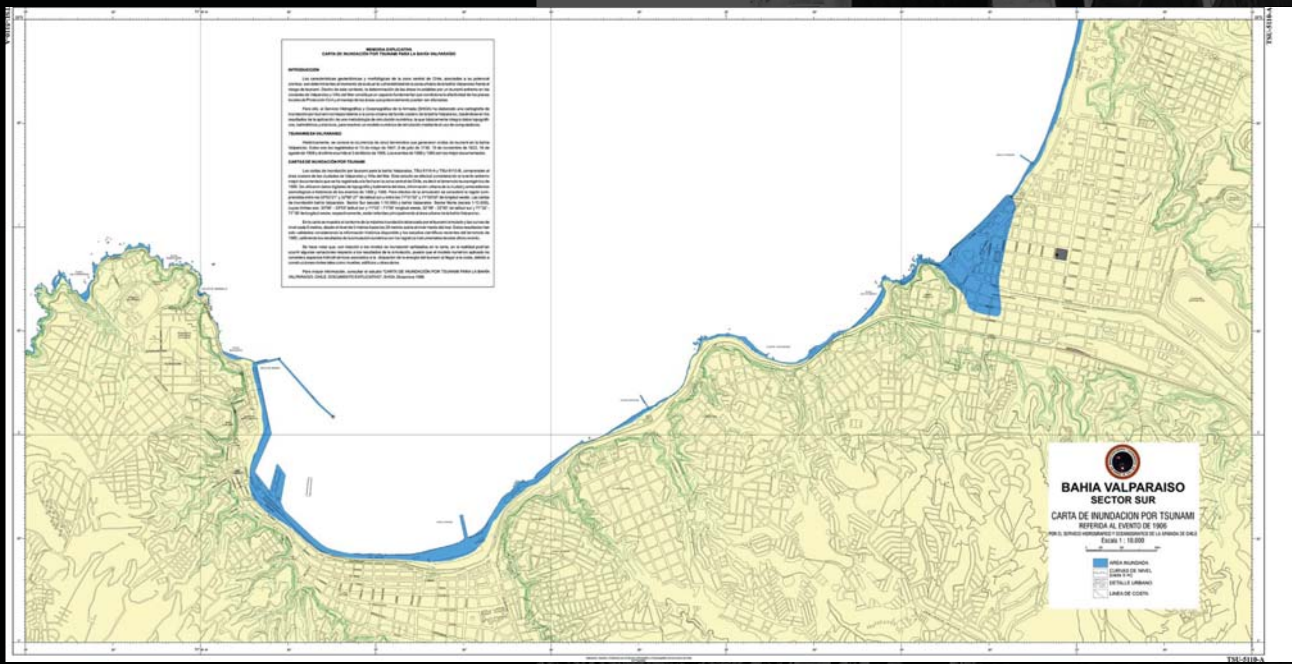
TSUNAMI HAZARD

SHOA Inundation maps





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TSUNAMI HAZARD

EARTHQUAKE SCENARIOS

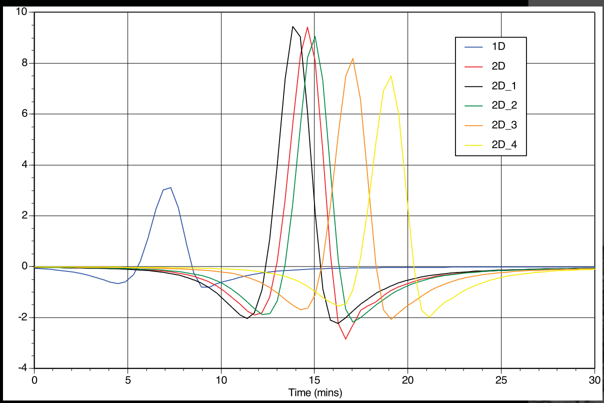
We generate a set of tsunami scenarios at the site of Valparaiso, associated to different “scenario” earthquakes that can be classified, according to their different:
a) magnitude,
b) occurrence period, Tm, to be intended solely for an engineering analysis, and
c) risk level:

Magnitude 7.0	Frequent	(Tm≈70-80 years)
Magnitude 7.5	Occasional	(Tm≈120-140 years, Strong)
Magnitude 7.8 (1985)	Sporadic	(Tm≈200-250 years, Very Strong)
Magnitude 8.3 (1906)	Rare	(Tm≈500 years, Disastrous)
Magnitude 8.5	Exceptional	(Tm≈1000 years, Catastrophic)

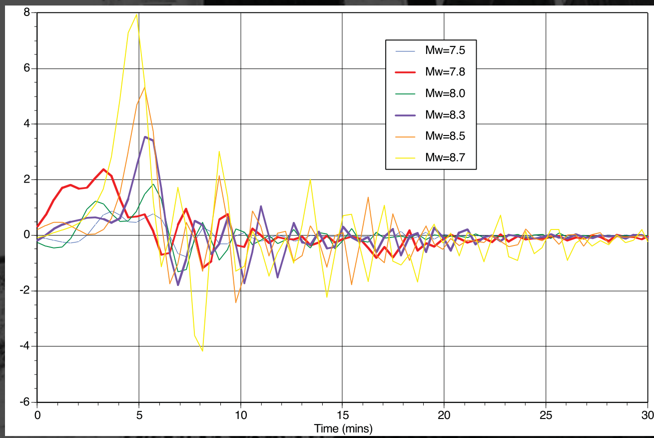
"MAR VASTO" - "Manejo de riesgos en Valparaiso"

TSUNAMI HAZARD

Laterally heterogeneous models & Extended sources



Tsunami signals for the reference case (1D) and different laterally heterogeneous models (2D).



Tsunami signals computed at Valparaiso site (about 50 km) for different magnitudes (from 7.5 to 8.7) considering extended source models.

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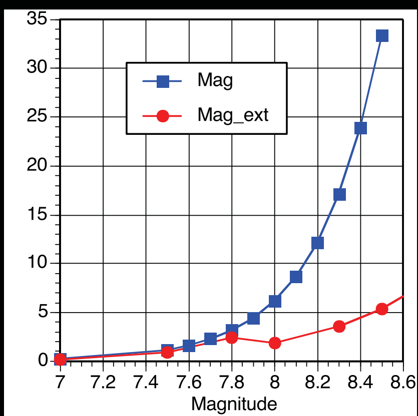
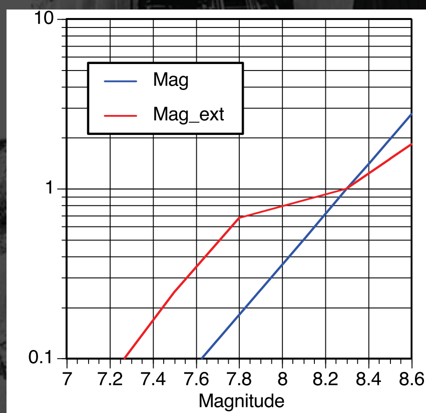
TSUNAMI HAZARD

Final remarks

Using as a base of knowledge the inundation map provided by SHOA (1999) associated to the 1906 event, an upper bound of the multiplication factor for the tsunami hazard associated to be used for the different scenarios can be read in Figure: the tsunami heights, computed with a scaled and an extended source, are plotted versus magnitude and the associated amplifications (using as reference the 1906 level) are shown:





a) Maximum height (for point and extended sources)
b) amplification compared to the reference event (1906 earthquake) for the scenario earthquakes considered.

Methodological references

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