The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA International Atomic Energy Agency

2142-22

Advanced Conference on Seismic Risk Mitigation and Sustainable Development

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Hazard scenarios: groundshaking (and tsunami) modelling for seismic input

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The Abdus Salam International Centre for Theoretical Physics

Advanced Conference on Seismic Risk Mitigation and Sustainable Development

Hazard scenarios: groundshaking (and tsunami) modelling for seismic input

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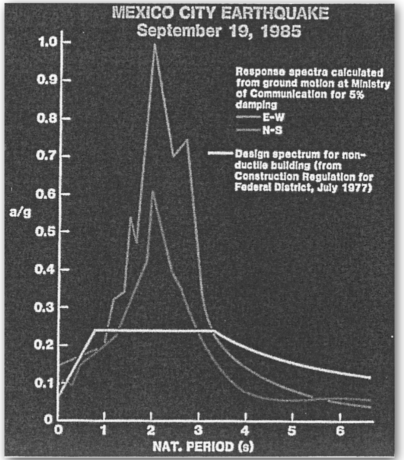
UNIVERSITÀ DEGLI STUDI DI TRIESTE

DiGeo
www.geoscienze.units.it

the road to (earthquake) safety...

Know the input - Bound the output...

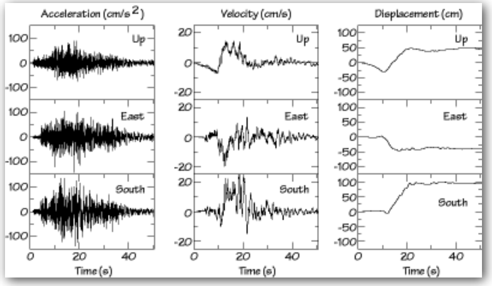


Mitigate the difference...

Road map

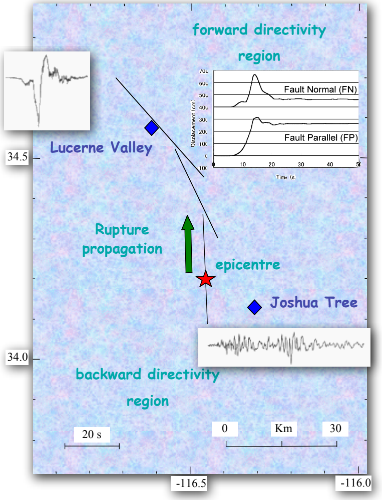
- Some remarks on SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Case studies
- A bird's eye on tsunami hazard assessment
  - Some physical concepts
  - Case studies

Source effects...



Michoacan, 1985

Fling & Directivity
aka
Near-field (& source)



Landers, 1992

Near fault ground motion

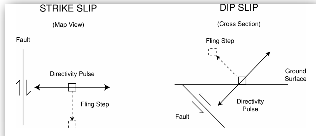


Fig. 4.3. Schematic diagram showing the orientations of fling step and directivity pulse for strike-slip and dip-slip faulting.

Peer report, 2001

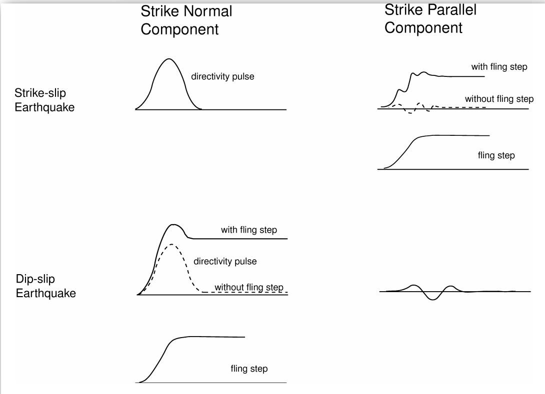
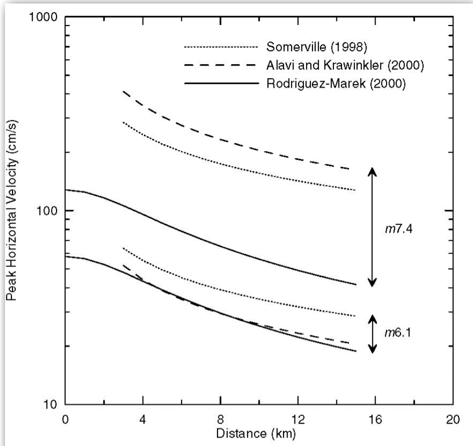


Fig. 4.4. Schematic diagram of time histories for strike-slip and dip-slip faulting in which the fling step and directivity pulse are shown together and separately.

Regression example...



Rodriguez-Marek (2000):
$\ln(PHV) = 2.44 + 0.5\,m - 0.41\,\ln(r^2 + 3.93^2)$

Somerville (1998):
$\ln(PHV) = -2.31 + 1.15\,m - 0.5\,\ln(r)$

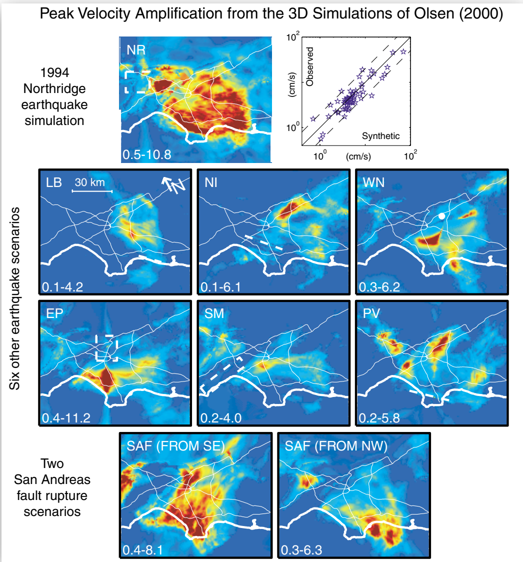
Alavi and Krawinkler (2000):
$\ln(PHV) = -5.11 + 1.59\,m - 0.58\,\ln(r)$

Peer report, 2001

Amplification patterns...

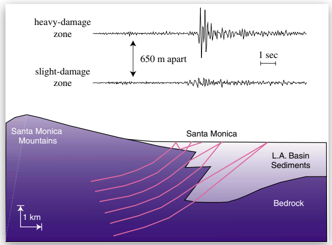
....may vary greatly among the earthquake scenarios, considering different source locations (and rupture ...)

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…

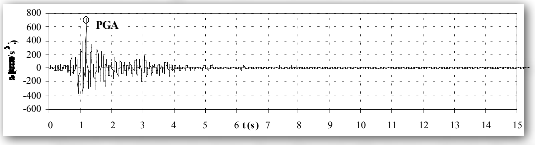


Figure 1 – Acceleration time history. Rocca NS record. 1971 Ancona earthquake (M_L=4.7)

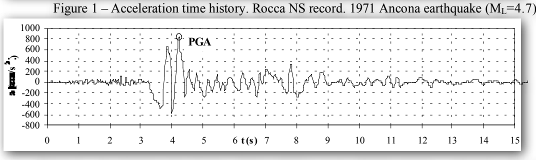
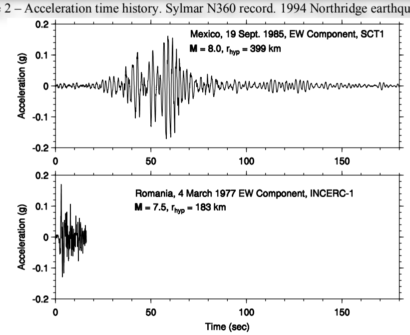


Figure 2 – Acceleration time history. Sylmar N360 record. 1994 Northridge earthquake (M_w=6.7)



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.

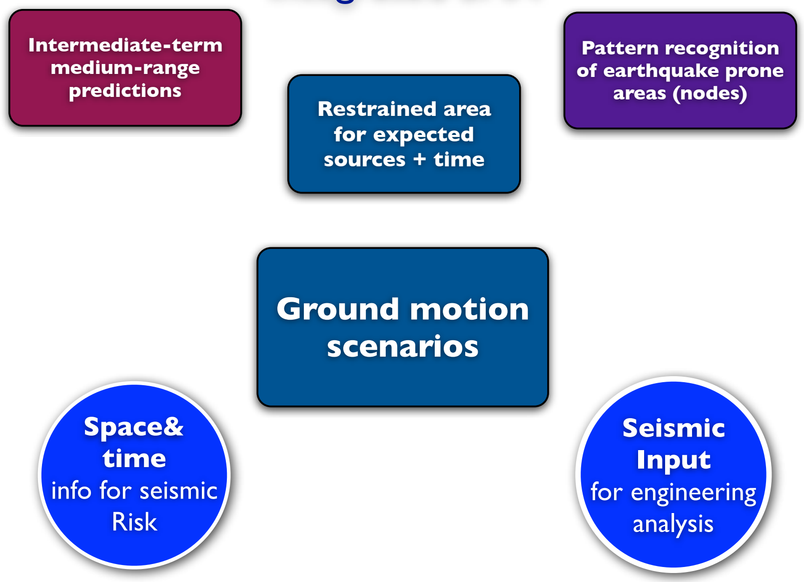
It is necessary to use a suite of time histories having phasing and spectral shapes that are appropriate for the characteristics of the earthquake source, wave propagation path, and site conditions that control the design spectrum.

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

Integrated SHA



Multiscale Integrated SHA

Ground motion scenarios

Regional seismic hazard scenarios
(ground motion at bedrock)

Time dependent neo-deterministic seismic hazard assessment

Seismic Microzoning
(including lateral heterogeneities)

Road map

- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Triest
  - 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

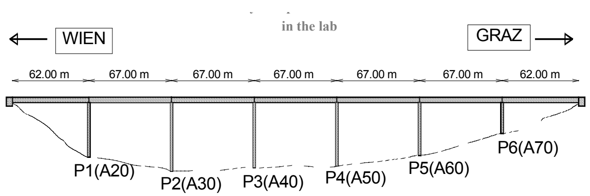
ARSENAL RESEARCH, Vienna, Austria; ISMES S.P.A., Bergamo, Italy; ICTP, Trieste, Italy; UPORTO, Porto, Portugal; CIMNE, Barcelona, Spain; SETRA, Bagneaux, France; JRC-ISPRA, EU.

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

Warth bridge

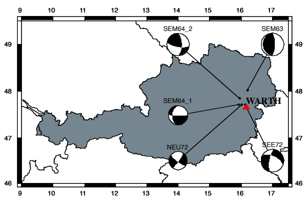
The bridge was designed for a horizontal acceleration of 0,04 g using the quasi static method.

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.



Warth bridge - Seismic sources

1) **Database of focal mechanism**



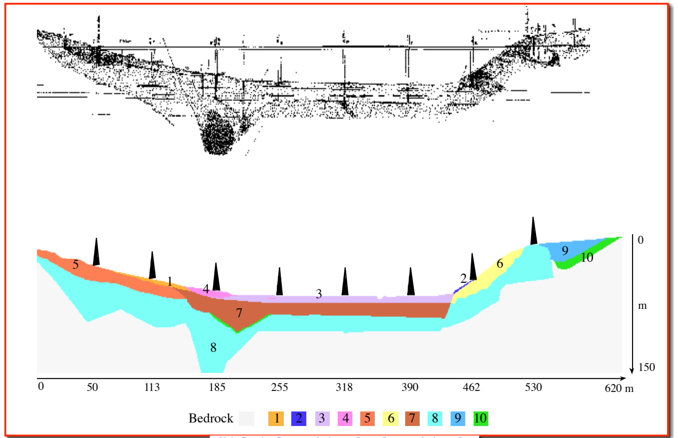
2) **Parametric study on focal mechanism:**
strike
dip
rake
depth

Maximum Historical Earthquake

Maximum Credible Earthquake

Maximum Design Earthquake

Warth bridge - Local model

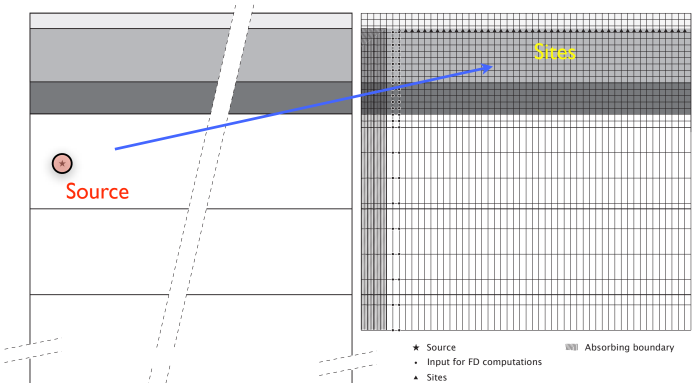


Unit	Density g/cm^3	P-wave velocity km/s	Q_P	S-wave velocity km/s	Q_S
1	1.5	0.30	40.0	0.20	15.0
2	1.7	0.49	40.0	0.25	15.0
3	2.0	0.70	50.0	0.26	20.0
4	1.8	0.70	50.0	0.29	20.0
5	2.3	0.80	50.0	0.30	20.0
6	2.3	0.80	50.0	0.40	20.0
7	1.8	1.70	50.0	0.50	20.0
8	2.3	2.10	150.0	1.00	60.0
9	2.3	3.00	150.0	1.90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

Methodology - Hybrid technique

Modal summation

Finite Differences

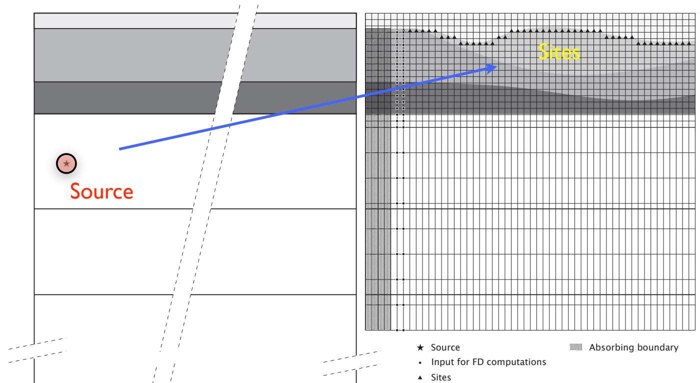


Material	Density (g/cm^3)	Vp (km/s)	Qp	Vs (km/s)	Qs
Air	0	0	0	0	0
Sed1	1.8	0.8	100	0.4	50
Sed2	1.9	0.9	100	0.5	50
Sed3	2.0	1.0	100	0.6	50

Methodology - Hybrid technique

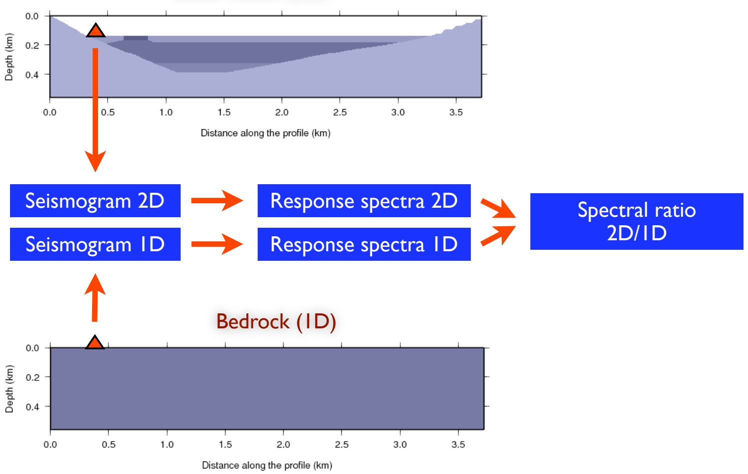
Modal summation

Finite Differences

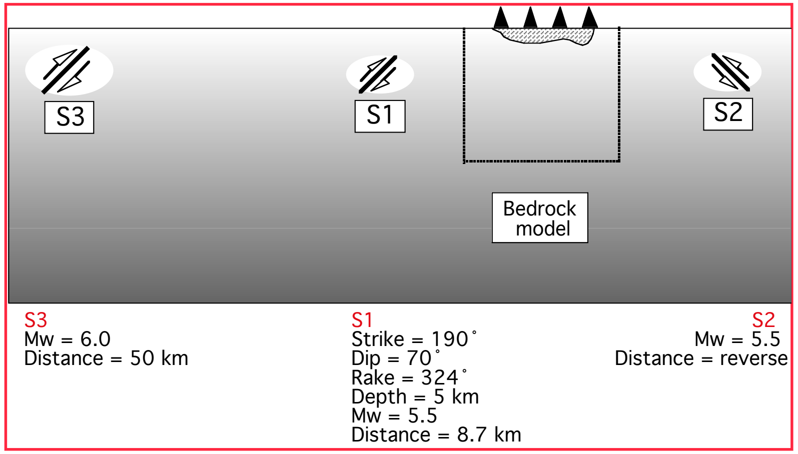


Material	Density (g/cm^3)	Vp (km/s)	Qp	Vs (km/s)	Qs
Air	0	0	0	0	0
Sed1	1.8	0.8	100	0.4	50
Sed2	1.9	0.9	100	0.5	50
Sed3	2.0	1.0	100	0.6	50

Methodology- 2D/1D spectral amplifications



Different source-sites configurations

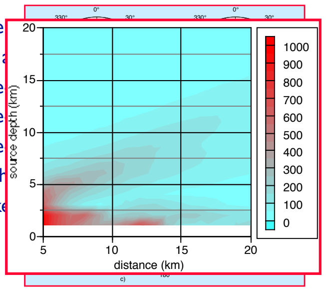


PARAMETRIC STUDY 1
Focal Parameters towards MCE

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.

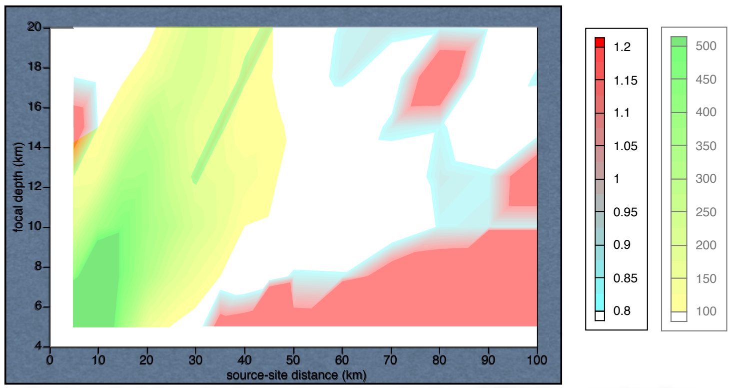
Longitude (°)	Latitude (°)	Focal Depth (km)	Strike (°)	Dip (°)	Rake (°)	Magnitude Ms (Mb)
16.120	**47.730**	**18**	**190**	**70**	**324**	**5.5 (4.9)**

1) Strike
2) Rake
3) Strike
4) Strike
5) Strike
6) Depth
(Strike



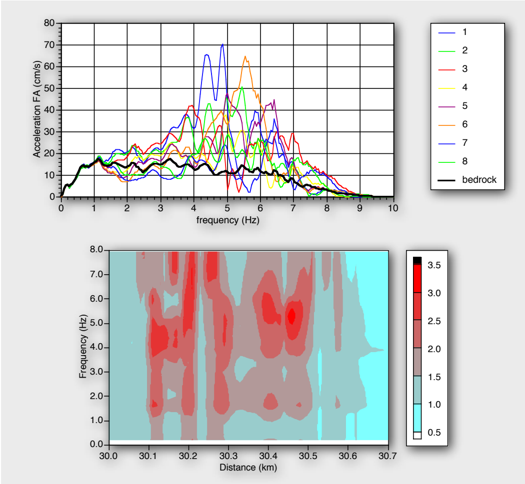
PARAMETRIC STUDY 2 - Fp towards 1Hz

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.



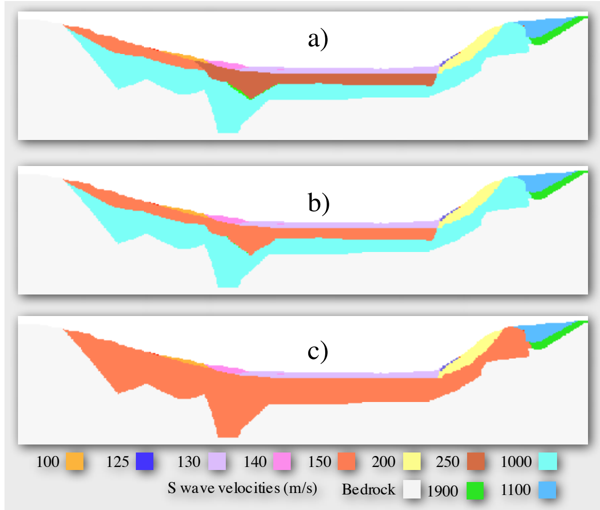
The results show that, in order to reach a relevant value of PGA (e.g. greater than 0.1g) in the desired period range (i.e. 0.8–1.2 s), an alternative and suitable configuration is a source
12 km deep at an epicentral distance of 30 km.

Parametric study 2 - FS & RSR



The results show that, 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

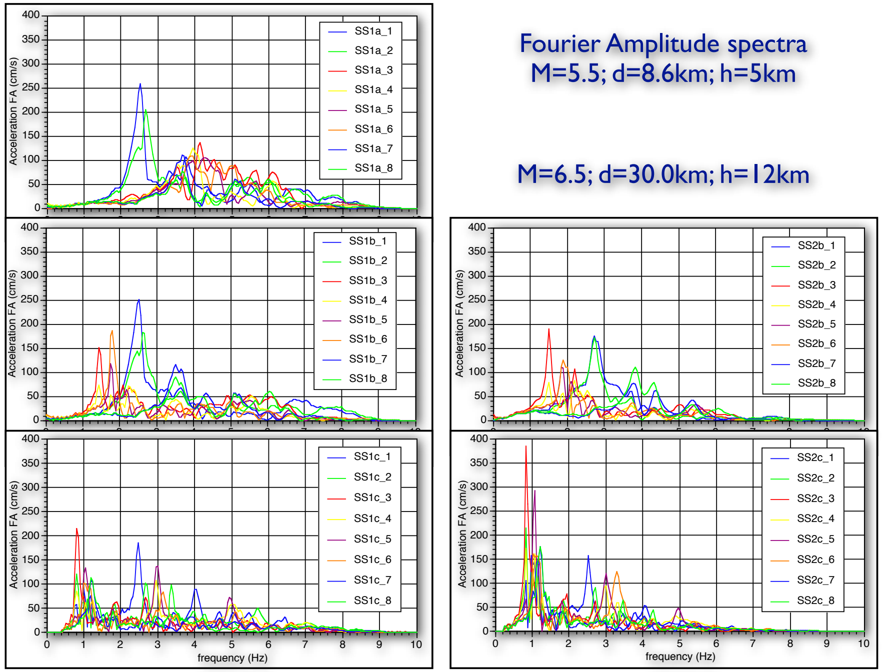


Local geotechnical models of Warth bridge section obtained lowering successively the S-wave velocities of the uppermost units

Fourier Amplitude spectra

M=5.5; d=8.6km; h=5km

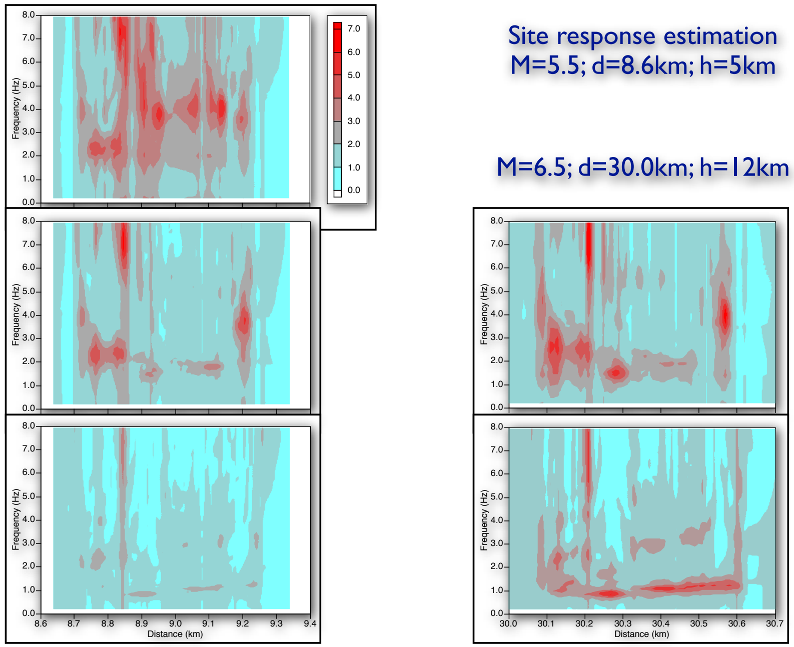
M=6.5; d=30.0km; h=12km



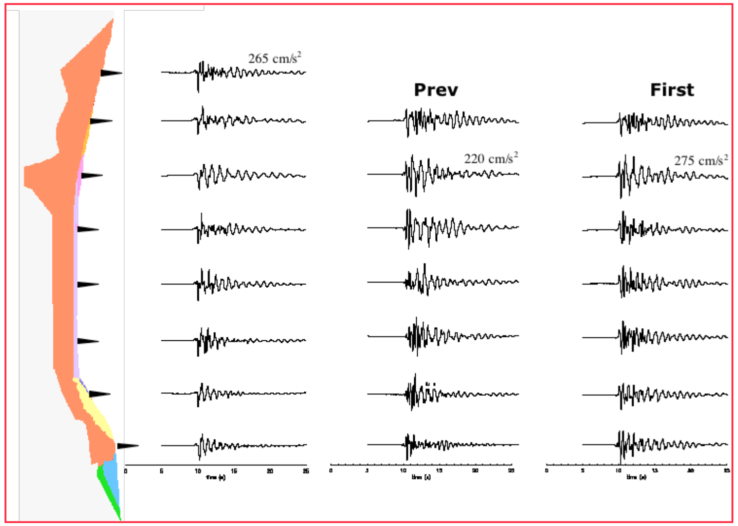
Site response estimation

M=5.5; d=8.6km; h=5km

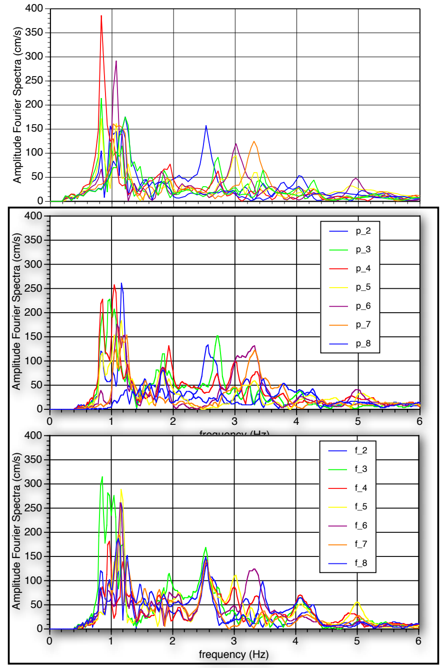
M=6.5; d=30.0km; h=12km



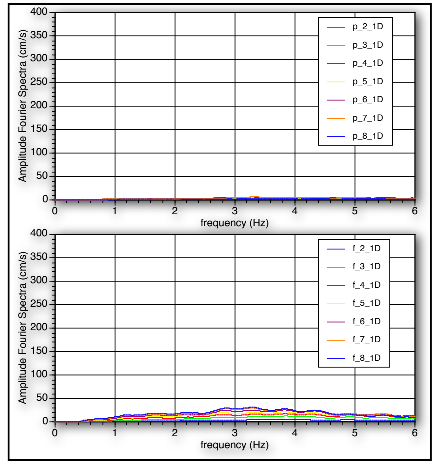
Synthetic accelerations and diffograms



Fourier AS of diffograms



Bedrock



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

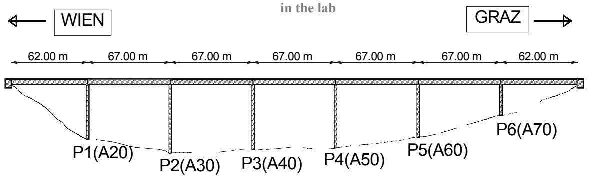
Physical piers A40 & A70 in the lab

Master experimental process

Numerical models for the substructured piers A20, A30

Numerical models for the substructured piers A50, A60

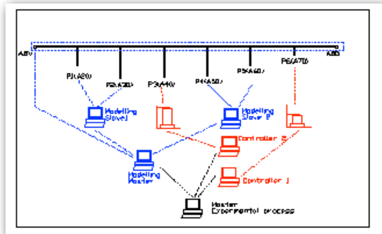
Numerical model for the deck and PSD master



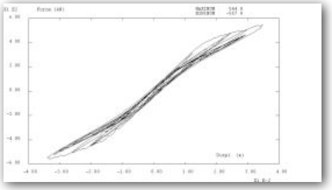
Warth Bridge

elsa

Implementation of PSD tests

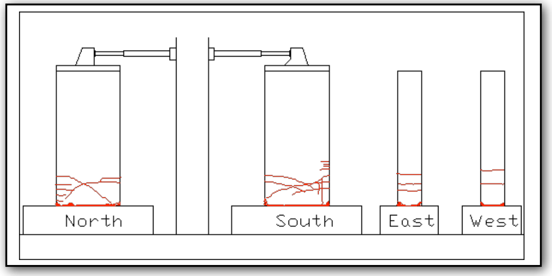


(a) physical piers in the lab, (b), schematic representation
(c) workstations running the PSD algorithm and controlling the test



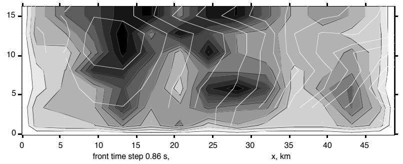
Force-displacement for Low-level earthquake - experimental results Pier A40

Identification of insufficient seismic detailing. tall pier A40, buckling of longitudinal reinforcement at h = 3.5m

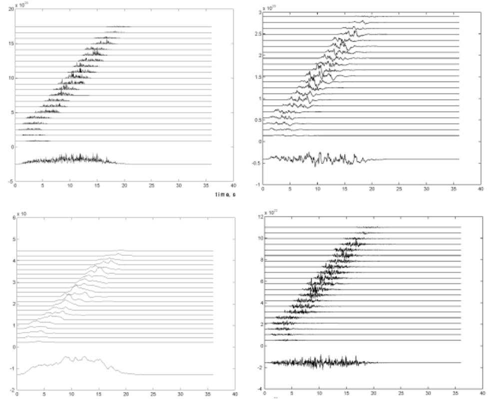


Damage pattern after the end of the High-Level Earthquake PSD test, short pier A70.

Extended source model



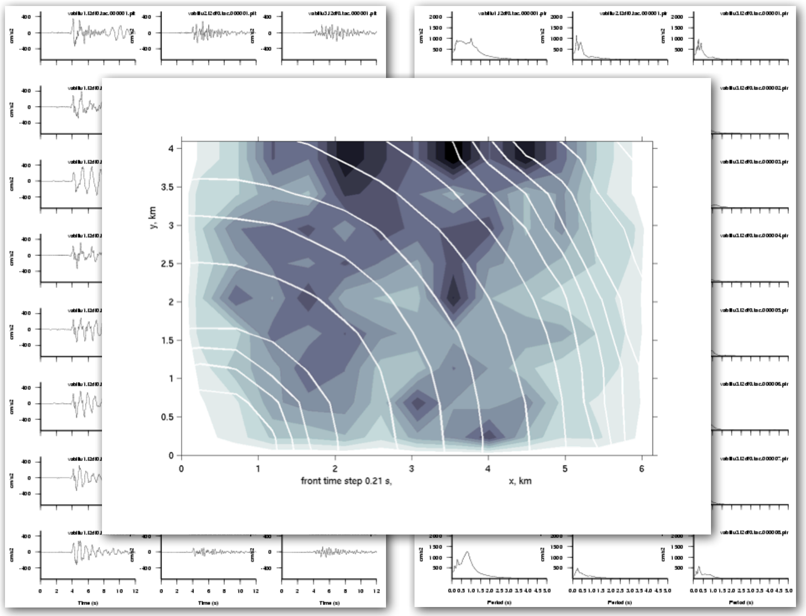
2-dimensional final slip distribution over a source rectangle, shown as a density plot. Preset magnitude value Mw=7.0. Rupture front evolution was simulated kinematically from random rupture velocity field.



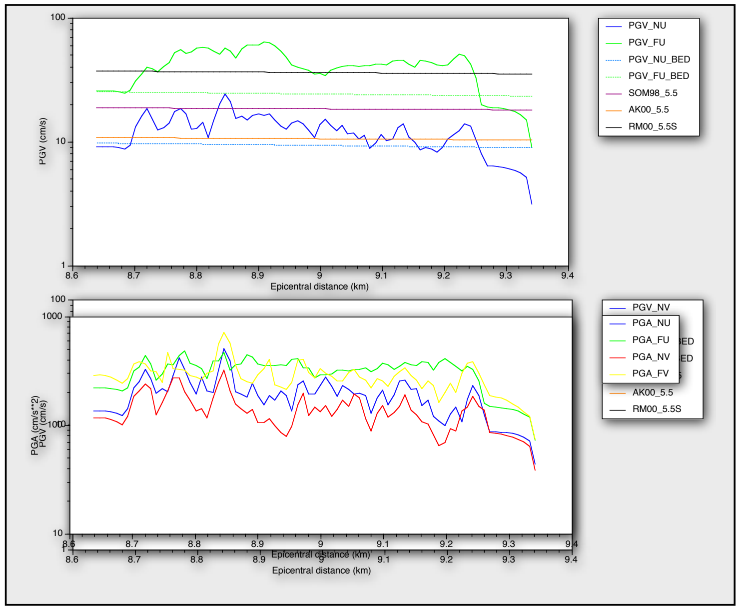
Space-time histories for each of 21 subevents of the simplified “line” source model of a simulated Mw=7 earthquake, and sum over subevents, giving the entire-source far-field time function

courtesy of Alexander Gusev

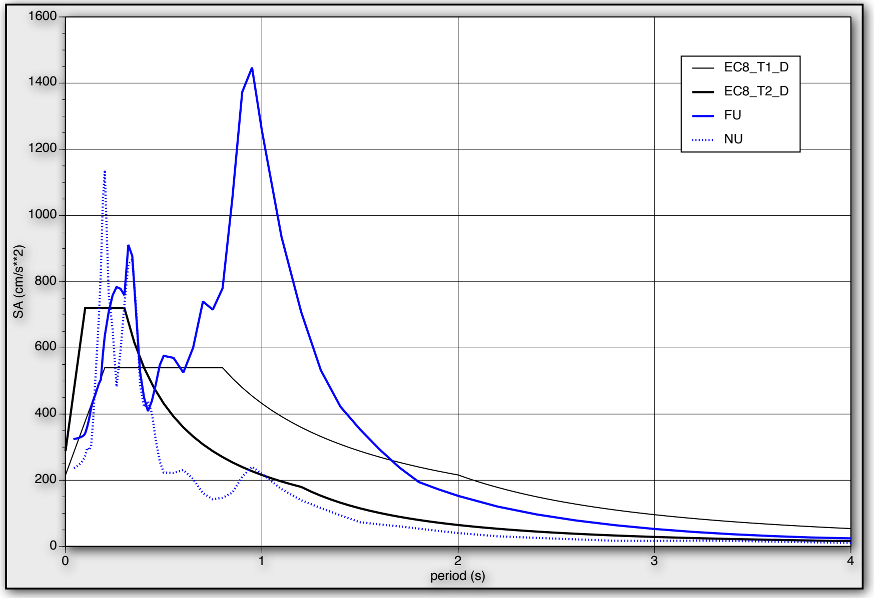
Directivity parametric study



Directivity & PGV - PGA



Directivity & SA



Road map

- Some remarks on sound SHA
  - Source & site effects
  - Integrated 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"

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)

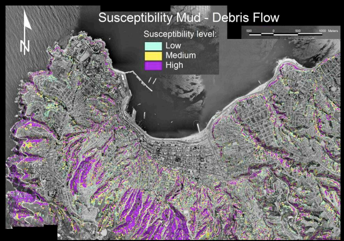
INVESTIGATION ON THREE HISTORICAL CHURCHES
(San Francisco, La Matriz, Las Hermanas de La Providencia)

INVESTIGATION ON A PILOT BUILDING STOCK
(Cerro Cordillera)

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

LANDSLIDE HAZARD

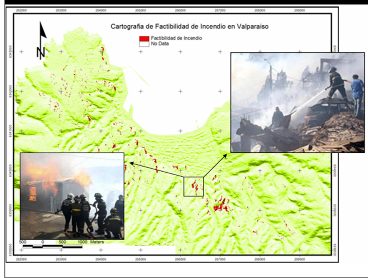
Cooperation with UC,
USM, OGP
cartography
quebradas Cerro Cordillera



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

FIRE HAZARD

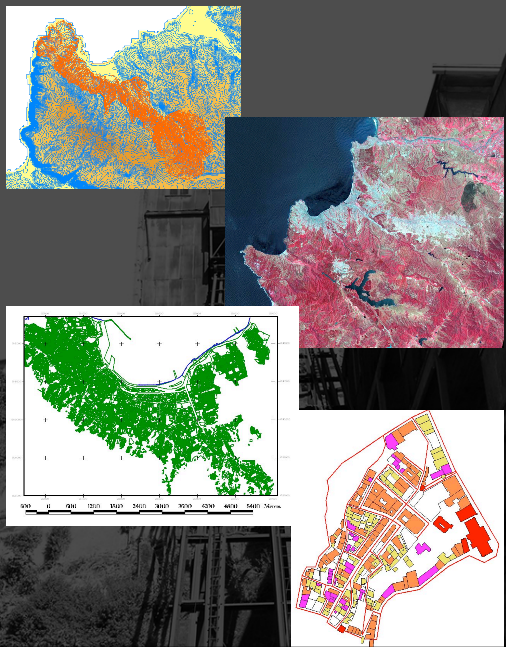
Cooperation with UC,
USM, OGP,OREMI, CORPO
DEI POMPIERI
cartography
churches protection
pilot study Cerro
Cordillera



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

GIS DATABASE

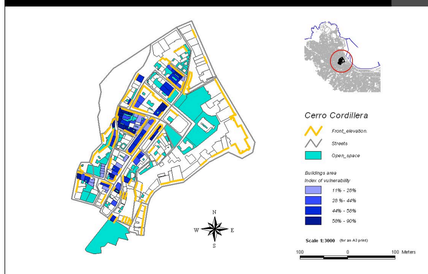
cooperation with
OGP,OREMI, SHOA,
FIREMEN CORP
cartography
aerial photos
vulnerability analysis



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

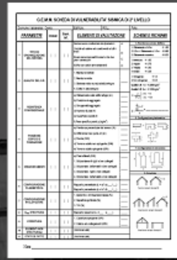
Urban planning analysis
Cerro Cordillera pilot area

In situ vulnerability
investigation
restoration proposals



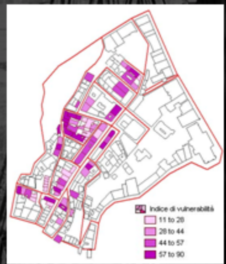
Area di studio

Particelle catastali di cui sono disponibili informazioni



Scheda di vulnerabilità sismica

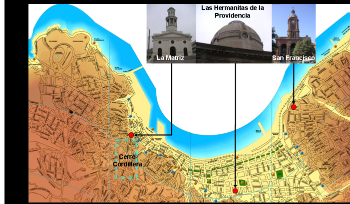
Edifici analizzati con la scheda strutturale



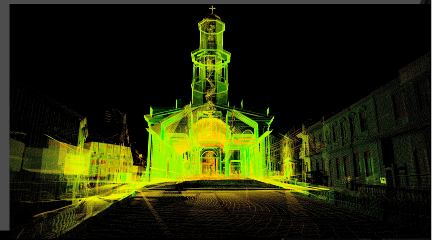
Distribuzione degli indici di vulnerabilità

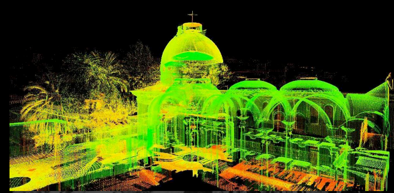
Analisi di vulnerabilità sismica del Cerro Cordillera mediante schede sintetiche

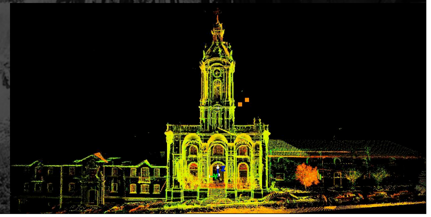
Laser scanner 3D



cooperation with
GEOCOM, OGP, FIREMEN CORP
La Matriz
San Francisco
Hermanas de la Providencia







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

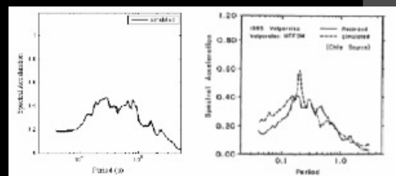
SEISMIC HAZARD

Validation

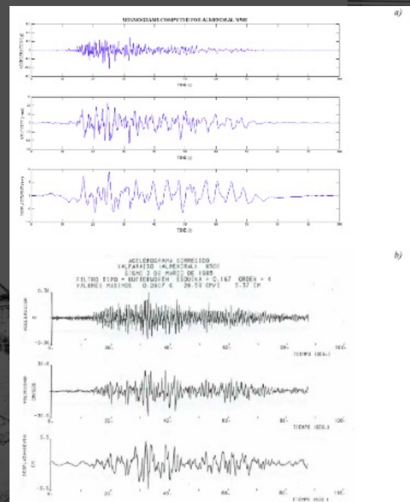
El Almendral station: acceleration, velocity and displacement for the 1985 event.

a) computed (unilateral rupture)

b) recorded.

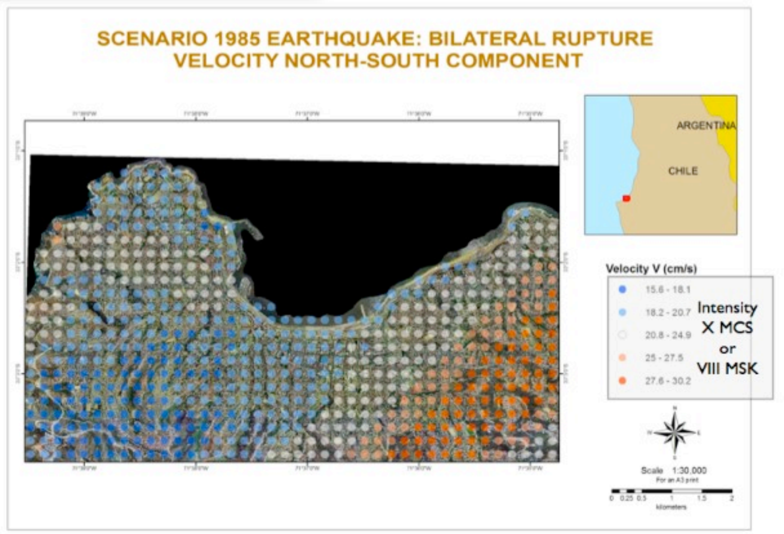


Comparison of response spectra: this study, recorded and the one simulated by Somerville et al., 1991.



SEISMIC HAZARD

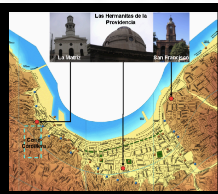
Urban scale

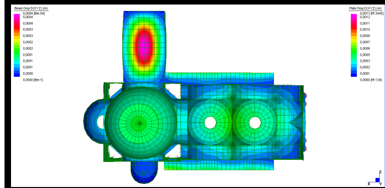


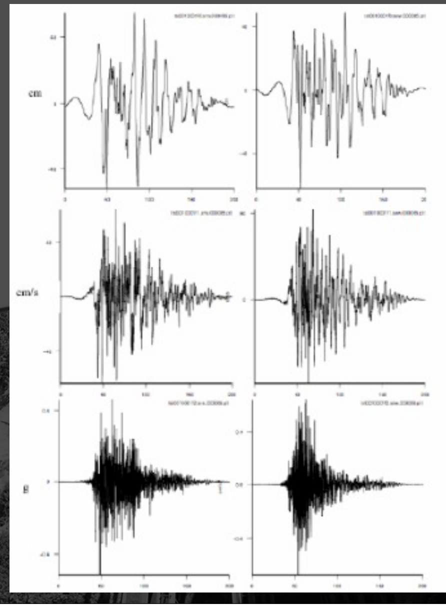
Groundshaking scenario in the Valparaiso urban area for the 1985 event.
NS component of velocities for bilateral rupture.

SEISMIC HAZARD

Seismic input for 3 selected churches





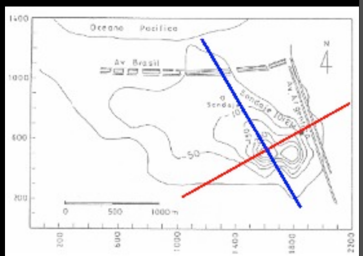


Example of seismic input computed at the La Matriz church: 1906 scenario, bilateral rupture.

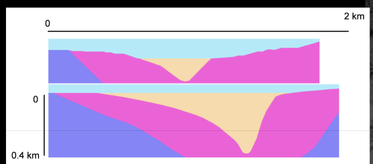
Displacements, velocities and accelerations for the two horizontal components of motion.

SEISMIC HAZARD

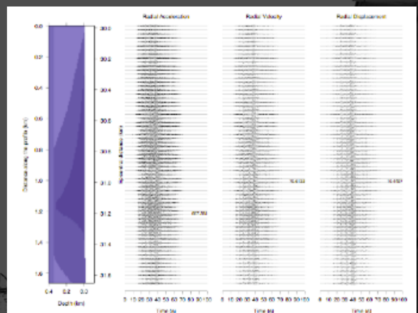
Profiles & site effects



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



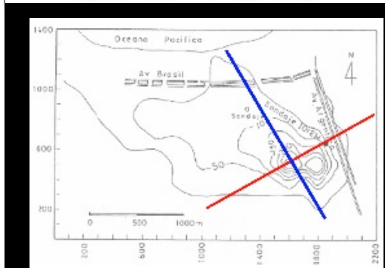
	Density (g/cm³)	Vp (km/s)	Vs (km/s)	Qp	Qs
Air					
Sed.1	1.5	1.365	0.665	80	40
Sed. 2	1.6	2.400	1.300	110	50
Bedrock	1.7	4.500	2.500	110	50

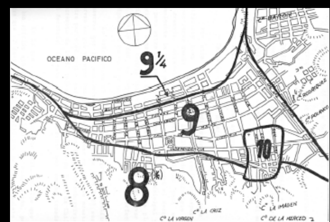


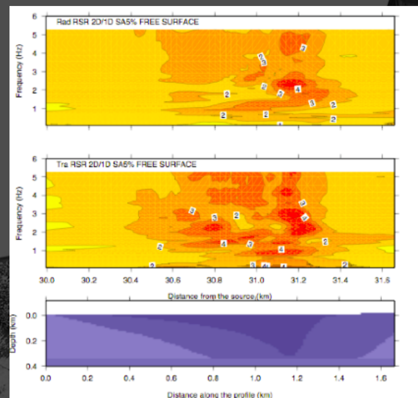
Radial component of motion along profile 2.
1906 scenario

SEISMIC HAZARD

Regional scale





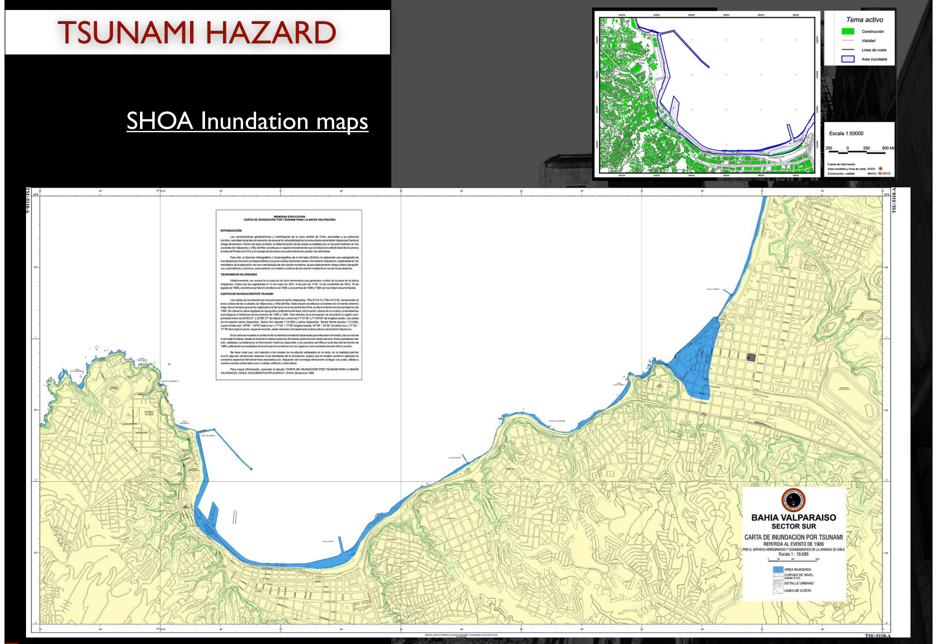


Spectral amplifications obtained along profile 2.
From top to bottom: radial and transverse component.

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

TSUNAMI HAZARD

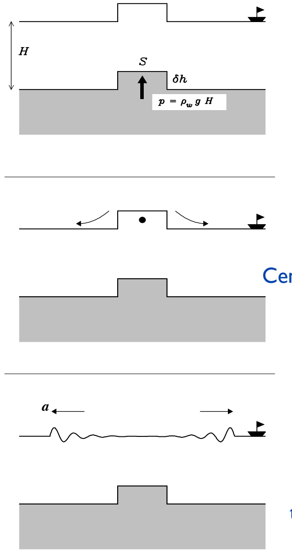
SHOA Inundation maps



Outline

- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology & Case studies
- A bird's eye on tsunami hazard assessment
  - Some physical concepts

Very basic tsunami physics...



Bottom uplift & Waterberg formation

Center of mass falls...

Potential energy goes to tsunami energy

Energy

$$E_R \approx 4.8 + 1.5M$$

$$E_T = \frac{1}{2}\rho g L \lambda (\delta h)^2$$

$$L \sim 10^6 m;\ \lambda \sim 10^4 m;\ \delta h \sim 5m$$

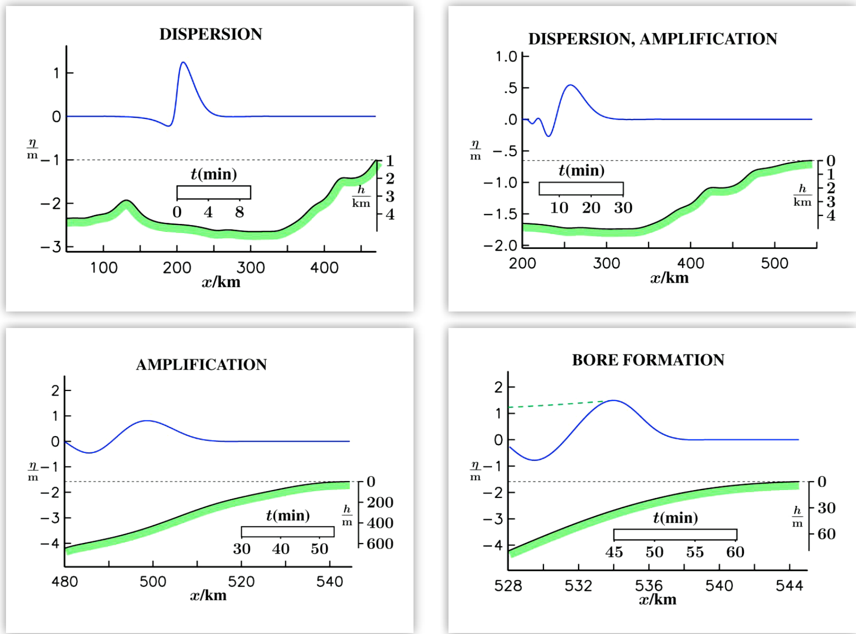
$$E_R \approx 10^{18} J \geq 10^2 E_T$$

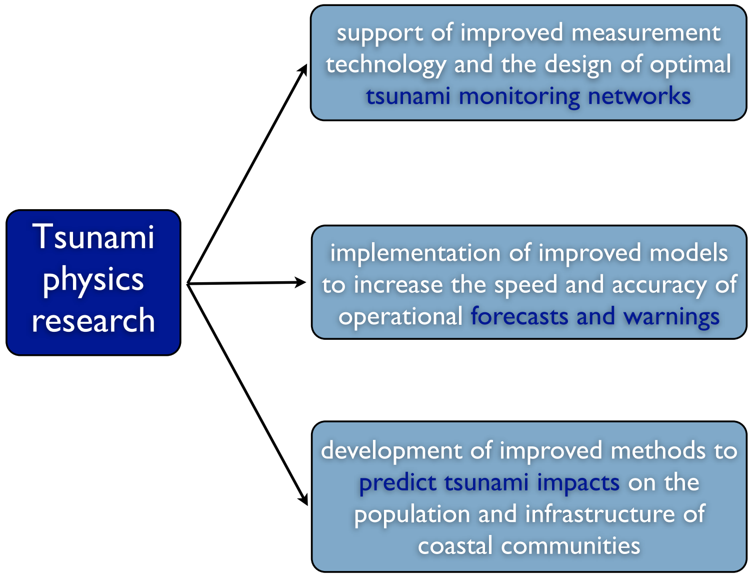
Wavelength

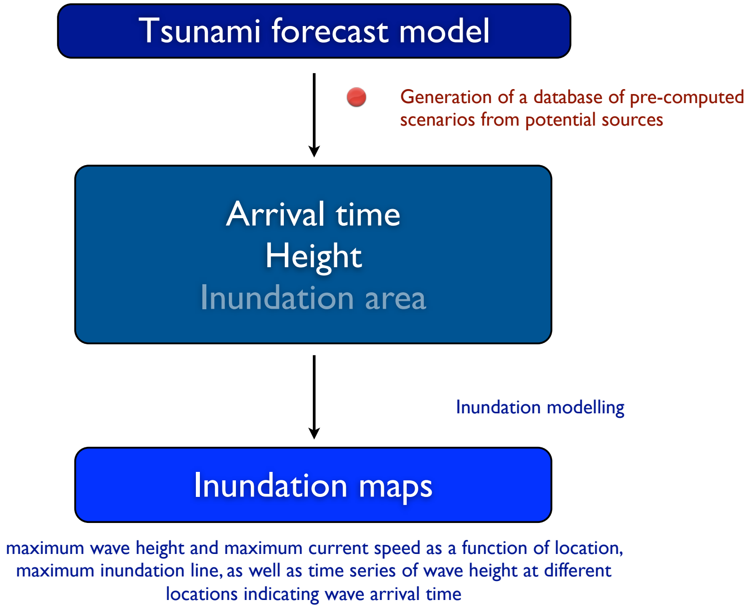
$$\frac{\lambda}{H} \sim 40;\ \frac{H}{a} \sim 3 \cdot 10^3$$

$$\lambda >> H >> a$$

Tsunami is a shallow-water gravity wave with great wavelength and tiny amplitude







Scenario based tsunami hazard assessment

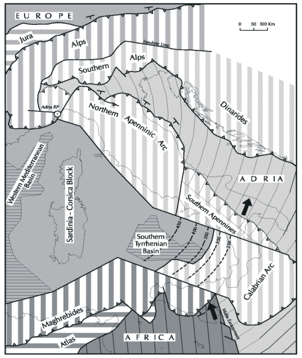
- Assess the potential threat posed by earthquake generated tsunamis on the coastlines.
- Compilation a database of potentially tsunamigenic earthquake faults, to be used as input in the definition of scenarios.
- Each Source Zone includes an active tectonic structure with a Maximum Credible Earthquake and a typical fault.
- Provide information of the expected tsunami impact (e.g. height and arrival times) onto the target coastline; it can be progressively updated as knowledge of earthquake source advances.

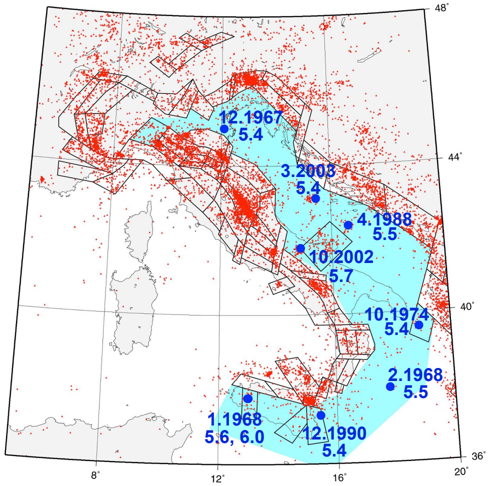
Road map

- Some remarks on sound SHA
  - Source & site effects
  - Integrated methodology
- Groundshaking scenarios modelling
  - Methodology & Case studies
- A bird's eye on tsunami hazard assessment
  - Some physical concepts
  - Case studies: Adriatic Basin

Paulatto M., Pinat T., Romanelli F., 2007.
"Tsunami hazard scenarios in the Adriatic Sea domain".
Natural Hazards And Earth System Sciences (on line), vol. 7, pp. 309-325.

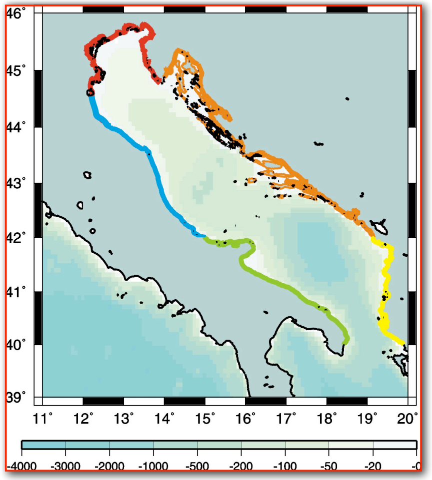
Seismicity in the Adriatic basin

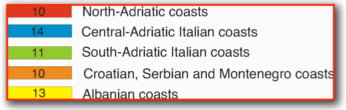




Earthquakes with M≥5.4 (1964-2004)

Historical tsunami in the Adriatic basin

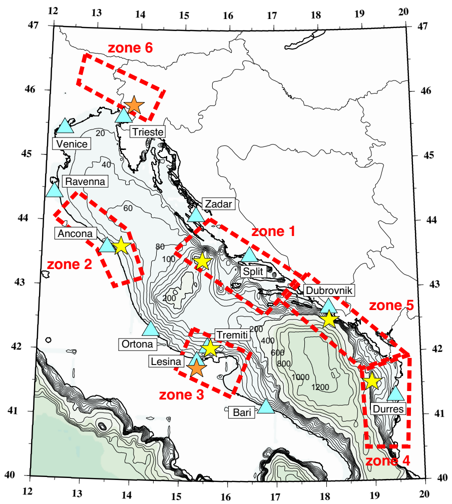




Tsunami reported in
ICTP Technical Report 2005:

CATALOGUE OF REPORTED
TSUNAMI EVENTS IN THE
ADRIATIC SEA
(from 58 B.C. to 1979 A.D.)

Hazard scenarios for the Adriatic basin

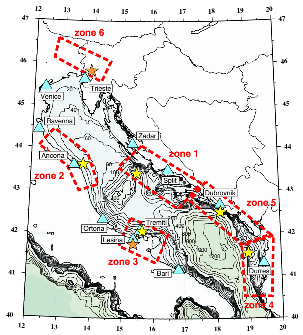


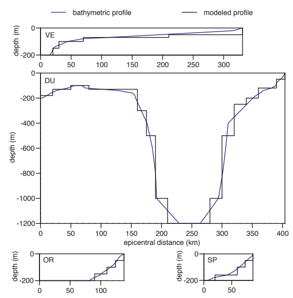
Bathymetric map of the Adriatic Sea. The bathymetric contours are drawn with a step of 20 m in the range from 0 to –200 m and with a step of 200 m in the range from –200 m to –1200 m.

The contours of the six tsunamigenic zones are shown in red, the blue triangles correspond to the 12 receiver sites, the stars correspond to the epicenters of the considered events (yellow: offshore, orange: inland).

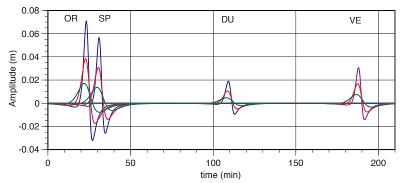
Paulatto M., Pinat T., Romanelli F., 2007. Tsunami hazard scenarios in the Adriatic Sea domain". Natural Hazards And Earth System Sciences (on line), vol. 7, pp. 309-325.

Tsunami scenarios in Adriatic Sea - Zone 1





Bathymetric profiles to (from top) Venice (VE), Durres (DU), Ortona (OR) and Split (SP)

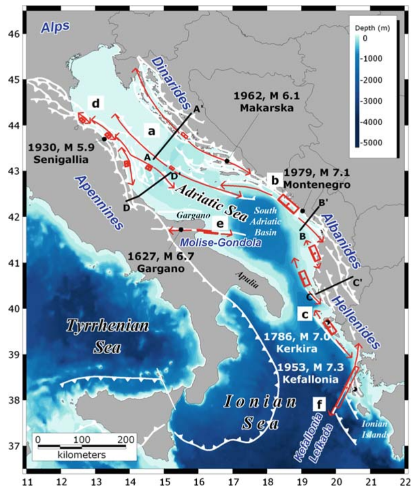


Synthetic mareograms for H =10 km (blue), 15 km (red), 25 km (green). Magnitude: M =6.5.

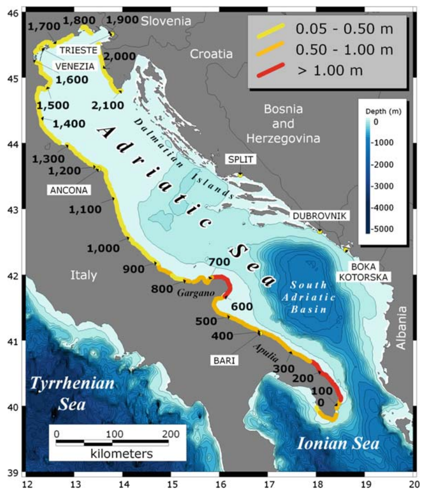
M	6.5			7.0			7.5			*Travel*
H (km)	10	15	25	10	15	25	10	15	25	*time (min)*
Durres	0.02	0.01	<0.01	0.11	0.06	0.03	0.60	0.33	0.15	*109*
Ortona	0.07	0.04	0.02	0.40	0.22	0.10	**2.25**	**1.22**	0.54	*23*
Split	0.06	0.03	0.01	0.32	0.17	0.08	**1.80**	0.98	0.43	*31*
Venice	0.03	0.02	0.01	0.17	0.09	0.04	0.97	0.53	0.24	*188*

Maximum amplitudes and related arrival times for different depths and magnitude

Updating...



Tectonic sketch map of the Adriatic basin.



Combined threat levels posed by all SZs

Tiberti et al., 2009. Scenarios of Earthquake-Generated Tsunamis for the Italian Coast of the Adriatic Sea, Pageoph, 165, 2117–2142.

Outline

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  - Case studies: Vietnam

Bisignano D., Romanelli F., 2010.
"Tsunami hazards scenarios in the Adriatic Basin and along the Vietnam coasts"
IAEA International Workshop on External Flooding Hazards at Nuclear Power Plant Sites

Vietnamese-Italian Bilateral Projects

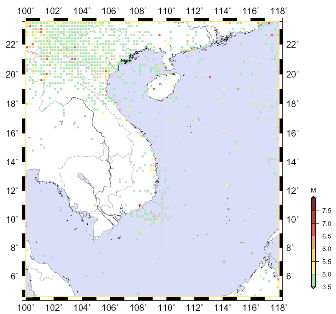
- Establishing appropriate approaches to increase Earthquake preparedness in Vietnam
- Advanced seismic micro-zoning for mega cities (Hanoi and Ho Chi Minh cities) in Vietnam
- Establishing appropriate approaches to increase Tsunami preparedness in Vietnam

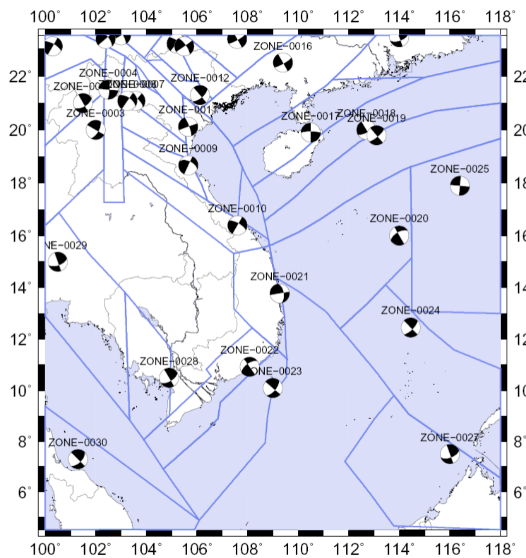
Bilateral projects approved in the Vietnamese - Italian Executive Programme in Science and Technology for the years 2002-2005, 2006-2008, 2009-2011

Institute for Geophysics, VAST - DST, University of Trieste

Seismic Zoning of Vietnam

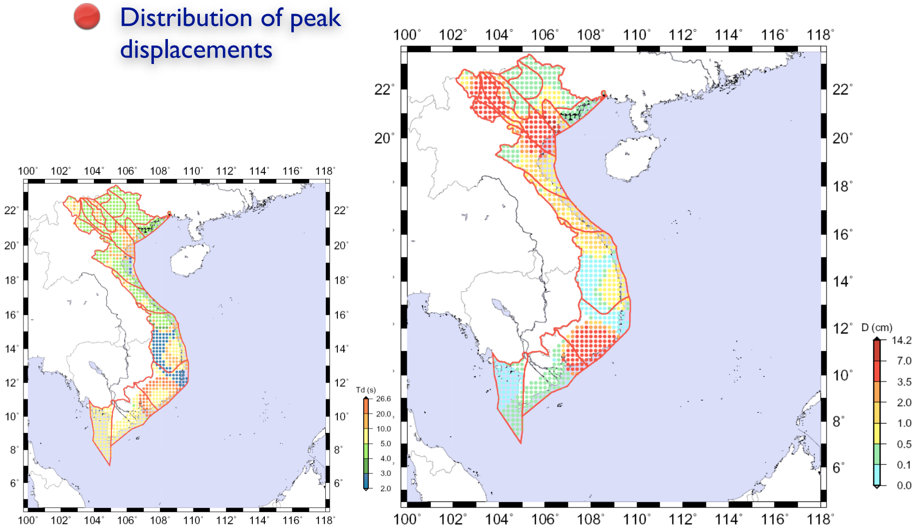
- Definition of seismic zones
- Magnitude discretization



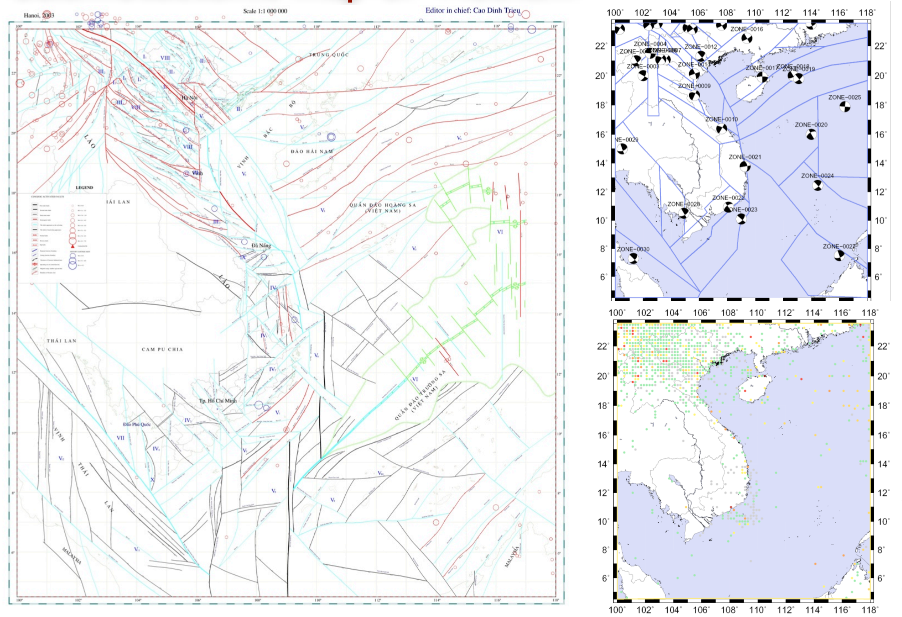


Seismic Zoning of Vietnam

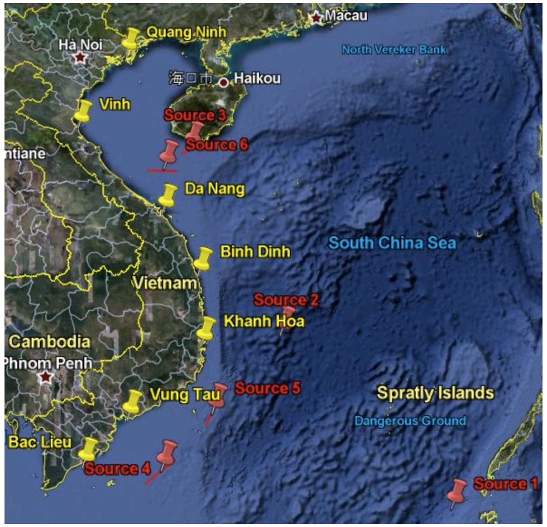
- Distribution of peak displacements



Seismotectonic map of Vietnam



Tsunami scenarios for the Vietnam's coasts

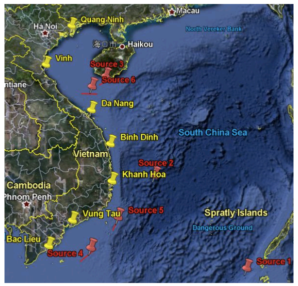


Map of the Southern Chinese Sea,

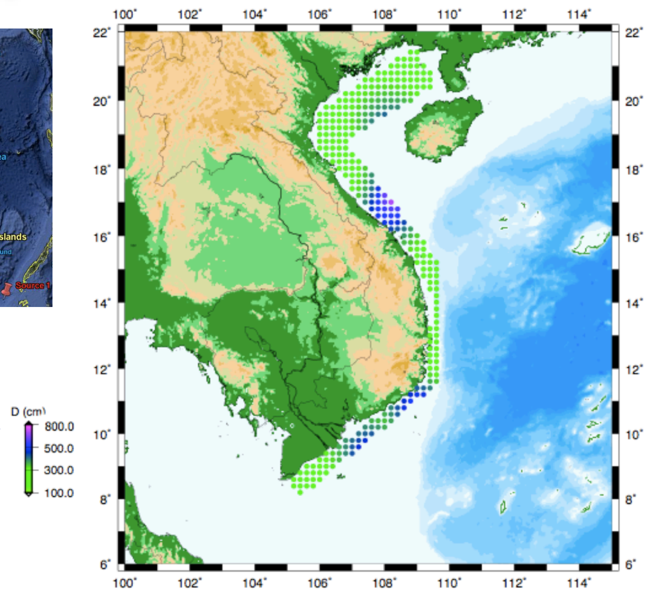
with the locations of the six selected tsunamigenic seismic sources (the red pins correspond to the epicenters),

and of the seven selected receiver sites (yellow pins) along the Vietnam coasts.

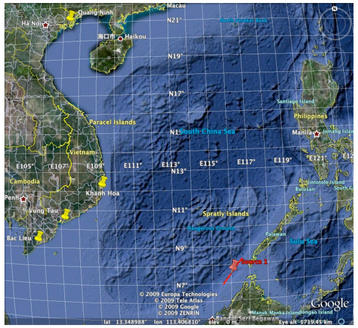
Tsunami computations - M_w=7.5

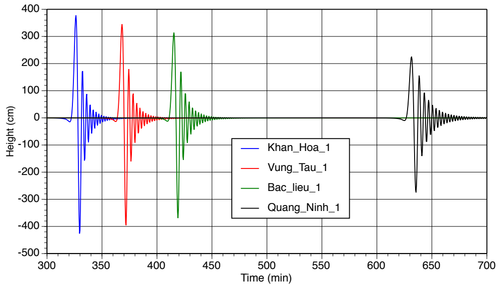


Distribution of the maximum positive tsunami wave heights along the Vietnam coasts computed considering the six sources for Mw=7.5



Tsunami scenarios - Source 1





Site	Khan Hoa	Vung Tau	Bac Lieu	Quang Ninh
Distance (km)	911	1028	1160	1736
Tmax (min)	205	229	261	397
Tmax – Tmin(min)	6	6	6	7
Strike max (°)	30	15	7.5	60
Max(cm) M=7	16	14	13	10
Max(cm) M=7.5	93	84	76	56
Max(cm) M=8	378	345	314	225

Synthetic tsunamigrams computed at the different sites for Source 1 scenario

Methodological references

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- Field, E.H., the SCEC Phase III Working Group (2000). "Accounting for site effects in probabilistic seismic hazard analyses of Southern California: overview of the SCEC Phase III report", Bull. Seism. Soc. Am., 90, 6B, p. S1-S31.
- PEER 2001/09 - Ground Motion Evaluation Procedures for Performance-Based Design, J. Stewart, S. Chiou, J. Bray, R. Graves, P. Somerville, N. Abrahamson.
- Panza, G.F., (1985). Synthetic seismograms: the Rayleigh waves modal summation. J. Geophys., 58, 125-145.
- Florsch, N., Fäh, D., Suhadolc, P. e Panza, G.F., (1991). Complete synthetic seismograms for high-frequency multimode SH-waves. Pageoph, 136, 529-560
- Fäh, D., (1992). A hybrid technique for the estimation of strong ground motion in sedimentary basin. Ph.D. thesis Nr. 9767. Swiss Fed. Inst. Technology, Zurich.
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- Panza, G.F., Romanelli, F. e Vaccari, F., (2001). Seismic wave propagation in laterally heterogeneous anelastic media: theory and applications to seismic zonation. Advances in Geophysics, 43, 1-95.