WORKSHOP

On Seramar Project

Bauhaus-Universität Weimar

EDAC

30 September-2 October HATAY

SEISMIC RISK ASSESSMENT AND MITIGATION IN THE ANTAKYA-MARAS REGION ON THE BASIS OF MICROZONATION, VULNERABILITY AND PREPAREDNESS STUDIES (SERAMAR)

Seismic microzonation techniques : Present possibilities and recommendations for an optimal impact on risk mitigation

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L'esprit de recherche au cœur des réseaux

Request from the organizers

- goal of workshop : "focus on seismic risk in dense urban environments, and the challenges of determining input motions in such settings"

- "to hear your views on whether earthquake scenarios fine-tuned to microzone studies or global field assumptions would serve the purposes better"

Outline

Introduction

- Microzonation studies : what for ?

Techniques for hazard zonation

- Regional Hazard : ? reference (rock) hazard
- Local hazard : Microzonation tools
  - Inventory, advantages and shortcomings

Learning from examples :

- Mexico City
- Tehran
- Nice

Conclusions / Recommendations

- (Ongoing studies in Beirut)

Microzonation studies : What for ?

a) **Technical viewpoint**

Local earthquake regulations superseding national regulations

Putting some urban planning constraints for future development

→ Emphasis on technical aspects

b) **Other viewpoint (efficiency ?)**

A tool for raising the awareness of seismic risk amongst local authorities, decision makers, business officials, etc…

The best way to have something done !

Improving the preparedness for emergency response

→ Emphasis on communication aspects

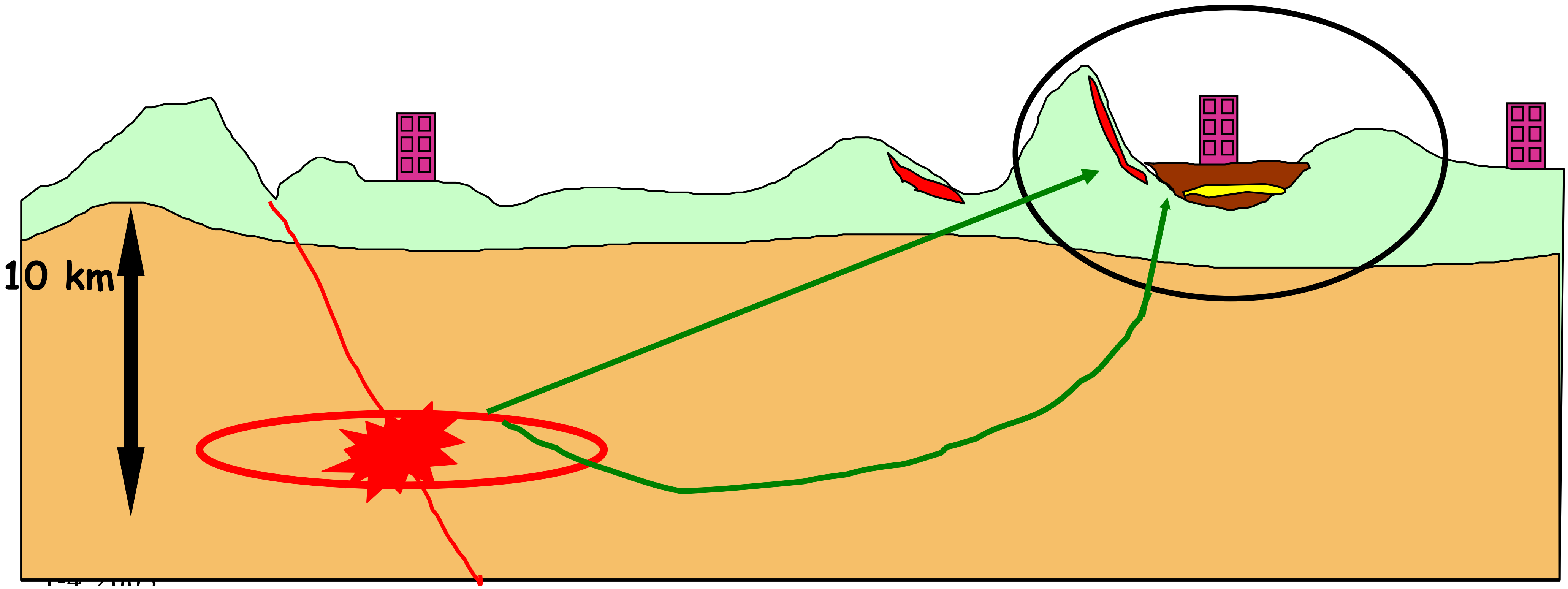
Physical phenomena at play

Ground shaking / Wave propagation

- source effects : wave radiation
- regional effects : deep propagation in the Earth's crust
- local effects
  - surface topography
  - alluvial deposits
  - urban effects

Soil failure

- liquefaction
- slopes / slides / falls

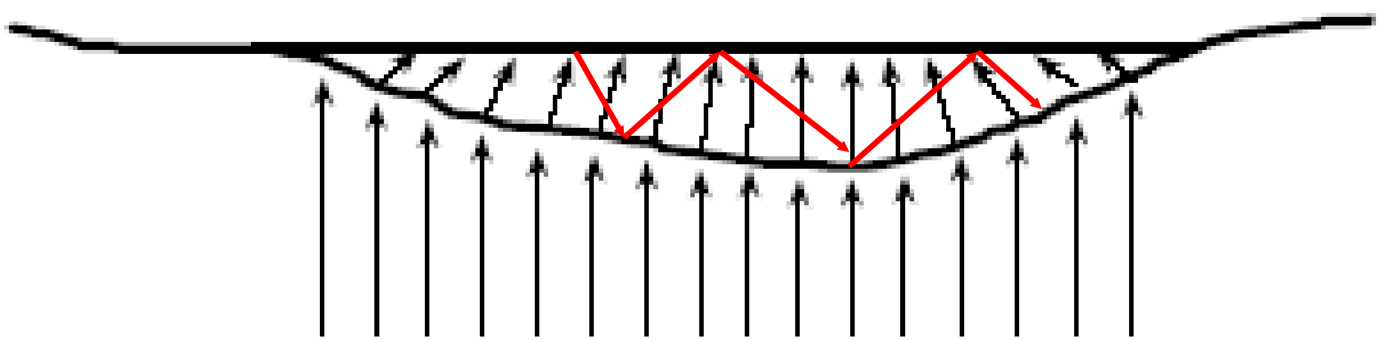


Resonance effects in sediments

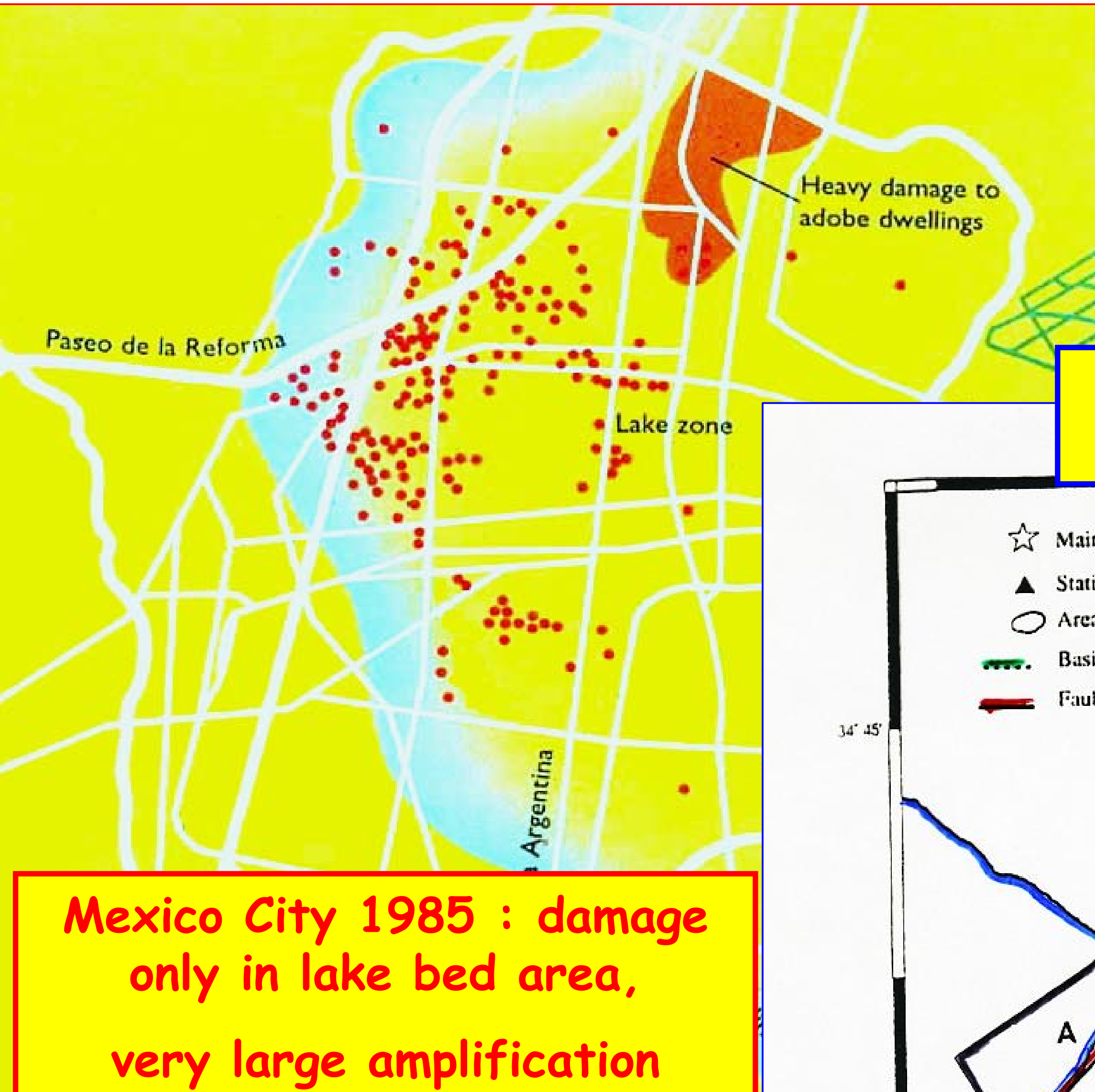
- **Wave field in surface deposits**
  - ➢ **Refraction, diffraction, focusing**
  - ➢ **Wave Trapping**
    - vertical reverberations
    - lateral reverberations

! + soil non-linearities !

- **Consequences**
  - ➢ **constructive interferences: amplification**
  - ➢ **trapping : prolongation**
  - ➢ **resonance at specific frequencies**



a few lessons

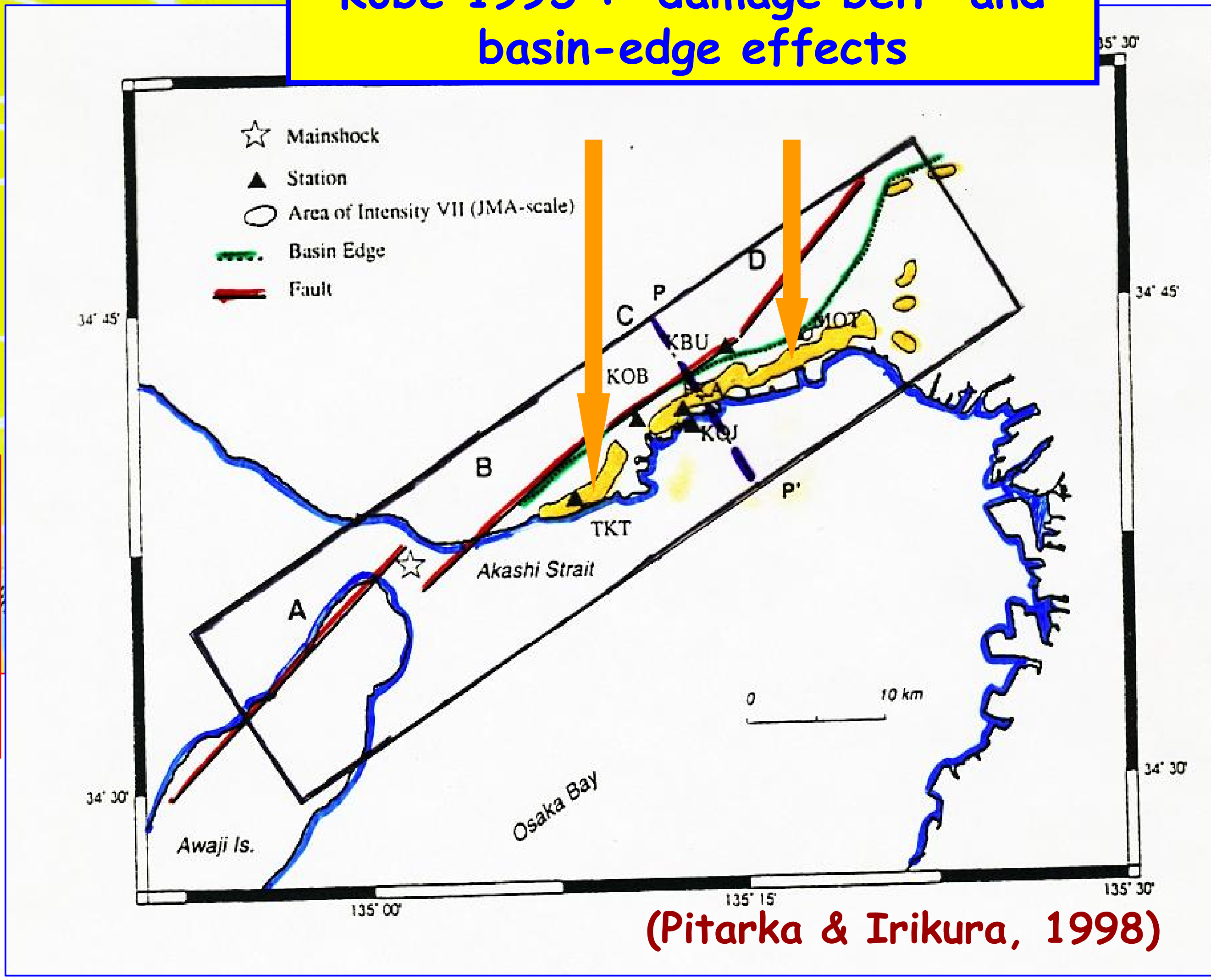


Mexico City 1985 : damage only in lake bed area,

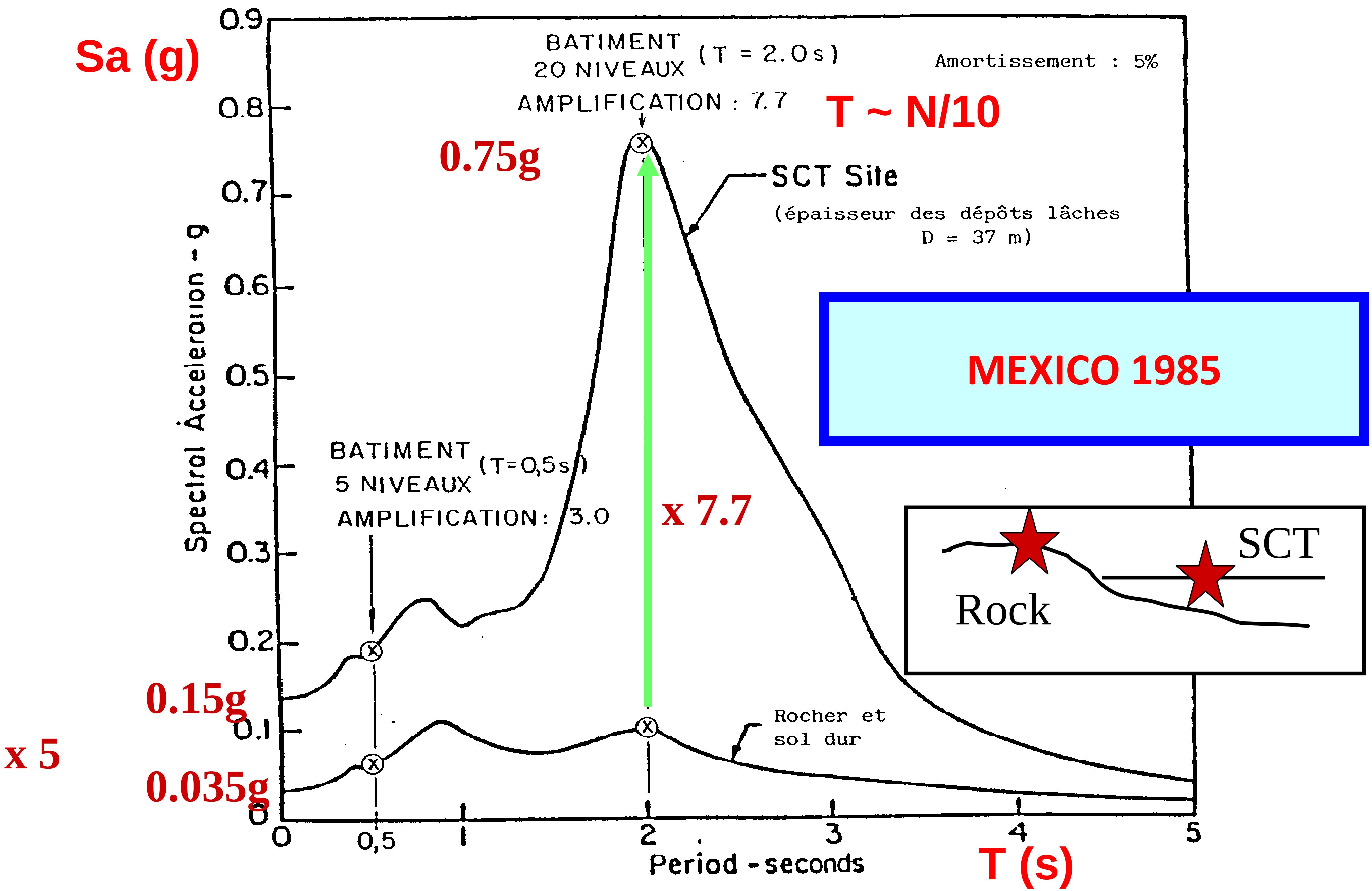
very large amplification

Non-Linear issue

Kobe 1995 : "damage belt" and basin-edge effects



(Pitarka & Irikura, 1998)


Sa (g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Spectral Acceleration - g
BATIMENT
20 NIVEAUX
(T = 2.0s)
AMPLIFICATION : 7.7
Amortissement : 5%
T ~ N/10
0.75g
SCT Site
(épaisseur des dépôts lâches
D = 37 m)
MEXICO 1985
BATIMENT
5 NIVEAUX
(T=0,5s)
AMPLIFICATION : 3.0
x 7.7
SCT
Rock
0.15g
x 5
0.035g
Rocher et
sol dur
0
0,5
1
2
3
4
5
Period - seconds
T (s)

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Introduction

Techniques for hazard zonation

- Regional Hazard : ? reference (rock) hazard
- Local hazard : Microzonation tools
  - Inventory, advantages and shortcomings

Regional hazard

Three options

- ➢ Official national seismic zonation (? UHS, T = 475 years)
- ➢ local PSHA study
  - (old national map, new knowledge on tectonics and faulting, ...)
- ➢ specific earthquake scenario
  - (historic event, "worst case", ...)
  - Best for civil defense preparedness and/or public awareness
  - Ground motion estimation : not so easy, many uncertainties (! source)
    - – May be quite different from an actual earthquake

Recommendation

- – In view of deriving design motion for local building codes, national map or local PSHA should be preferred
- – Keep national values unless very strong evidence to change it

Local Hazard : Microzonation tools

Various objectives

- Ground shaking hazard / liquefaction / slope instability
- Urban planning / Building code / emergency planning
- New buildings / existing building stock

Various kinds

- Direct / Indirect
- Instrumental / Numerical
- Qualitative / Quantitative

Local Hazard : Microzonation tools

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Inventory of available techniques : Indirect approach

First step of a multi-step approach, to be completed by

- Use of empirical correlations
- Numerical simulation
- Guidance for extrapolation or interpolation of site-specific measurements

Many possibilities / techniques

- Geology
- Geotechnics
  - SPT, CPT, borehole frilling, lab tests, …
- Geophysics : Target = V_{S30}, $V_S(z)$, f_0, Structure,
  - Invasive / Non-invasive
  - Active Seismics / microtremor (H/V, array) / gravimetry / GPR, …
- Remote sensing

Site characterization for building codes and microzonation studies

Today's practice : Building codes and GMPEs

- Standard = V_{S30} (NGA : + $Z_{bedrock}$)
  - Sometimes measured, often inferred (SPT, …)
  - To be considered as a **regional proxy** to more physical parameters (Impedance contrast, soil thickness)
  - **Should be adapted regionally**
  - Often criticized, but no other fully achieved alternative proposal
- Other possibilities (rare)
  - fundamental frequency

Looking for alternatives ?

- Should combine simplicity, cost effectiveness, and physical relevance
  - ? what can be done with ambient vibrations ?
- Example (f_0, V_{SZ}) : Better than V_{S30} (f_0 alone also better than V_{S30})
  - Background idea : coupling information on impedance contrast, velocity and thickness

Other proxies to site conditions for wide regional use (shake maps, hazard curves)

Inventory of possibilities

- Mandatory : available from remote sensing
- slope
- ? Other : f_0, …

SHOULD NEVER BE USED FOR MICROZONATION / DESIGN PURPOSES

Robustness for different data subsets (California vs Italy or Turkey ???)

is a weak correlation better than nothing ?

- Tests in GMPE

Inventory of available techniques : Direct approach

Seismological measurements

- permanent SM stations / temporary WM experiments
- various processing techniques
  - (SSR, GI, HV)
- Actual amplification / Weak motion only / Requires Extrapolation

Numerical simulation

- A wide variety
  - numerical schemes
  - Geometry / Rheology / near or distant source
- Verification and validation issues
- Sensitive to assumptions and parameters (measured / guessed)

Direct instrumental estimation of site amplification

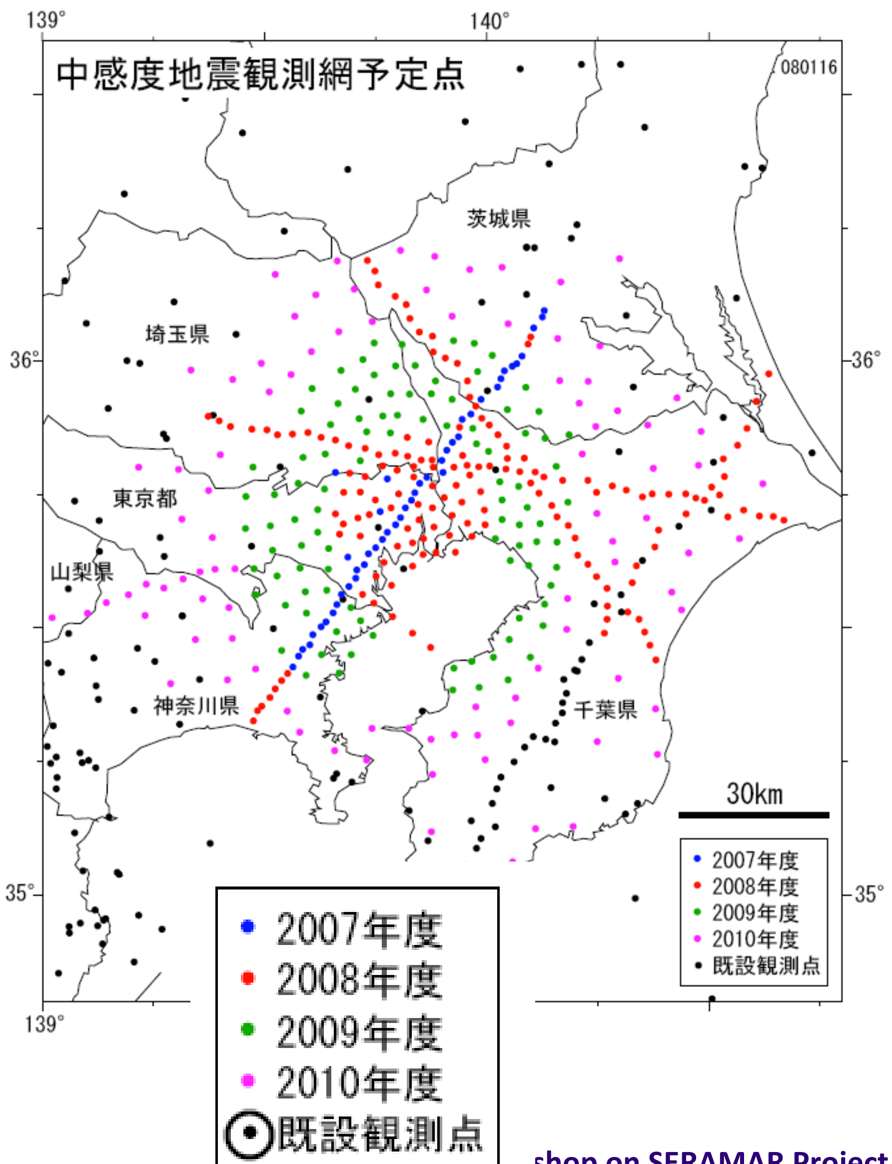
Instruments

- Permanent Strong Motion stations :
  - The best (if strong earthquakes)
- Temporary Weak Motion local network :
  - actual site amplification
  - but only in the linear range : NL reductions to be applied (not straightforward)

Processing Techniques

- Single station estimates : H/V from earthquakes
  - not recommended for design : only "indirect" information on f_0
- Site / reference spectral ratio
  - ➔ relative estimate, correction may be needed
- Generalized inversion techniques ➔ "average" reference
  - require sensitive instruments
- (more sophisticated : 2D arrays, Vertical arrays, Phase / duration analysis)
  - Not yet used for microzonation studies

Example : Ongoing studies in Tokyo (dedicated semi-permanent array)



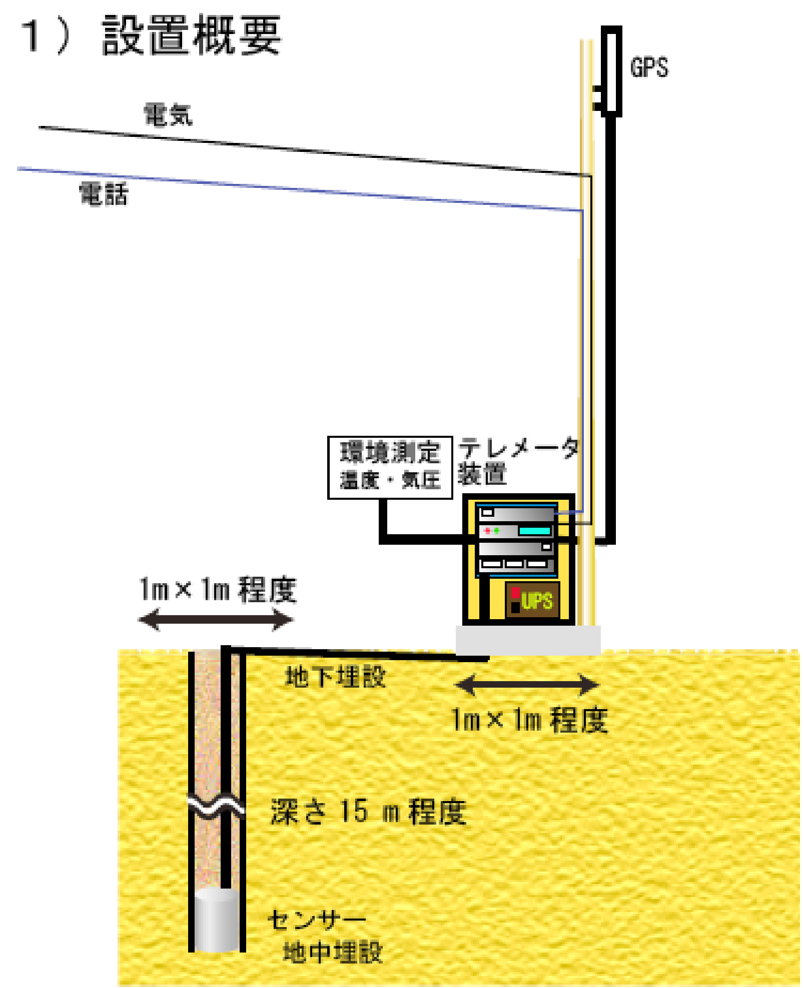


図１．地震観測装置設置概要

(Courtesy : T. Yamanaka / S. Tsuno, TITech)

Capability of numerical simulation techniques

A wide variety

- **Different sophistication levels**
  - 1D /2D/3D
  - Linear / Linear Equivalent / Non-Linear
  - Near source / Distant source
- **Various numerical schemes**
  - BEM, FDM, FEM, SEM, DGM, DEM, …

An invaluable tool in understanding the physics of site effects

BUT …

Capabilities of Numerical Simulation 2

Verification / validation issues

- still faces big challenges for actually predicting them for complex 3D structures. Numerous sophisticated codes do exist, but their use without due caution can be harmful
- Verification = evaluate the accuracy of current numerical methods when applied to realistic 3D applications
  - ➔ cross-checking that different codes provide similar results on same cases
- Validation = (successful) comparison with instrumental observations
  - ➔ quantify the agreement between recorded and numerically simulated earthquake ground motion
  - – (source + path + site)
- Recent initiatives / projects in Europe
  - SPICE, QUEST, NERA
  - ESG2006, Cashima

Present capabilities : at best frequencies around 4-5 Hz at reach ?

(In optimal conditions – rarely met in standard studies)

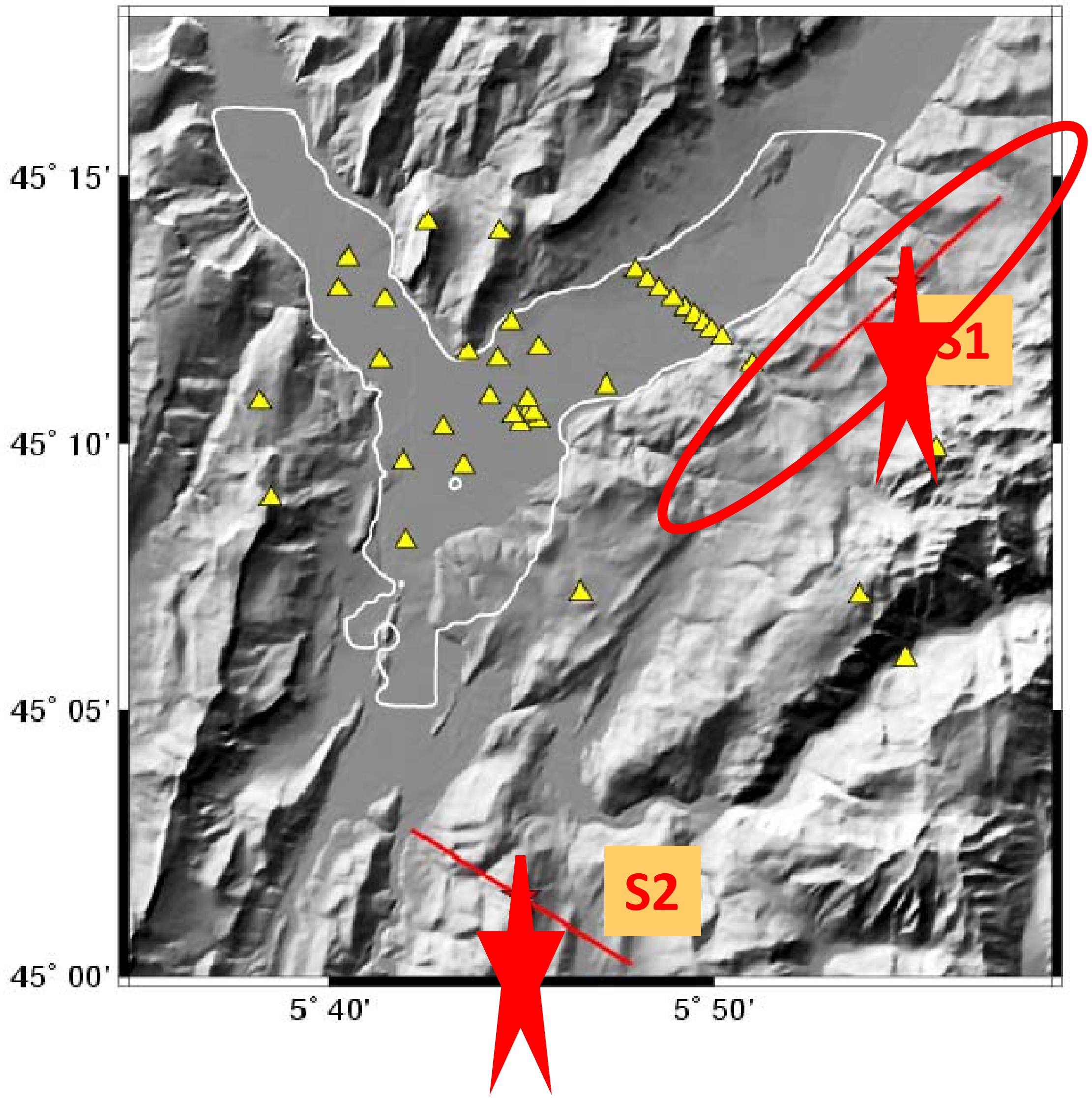
Example : the ESG2006 3D benchmark (Grenoble)

2 real weak events

- W1, W2

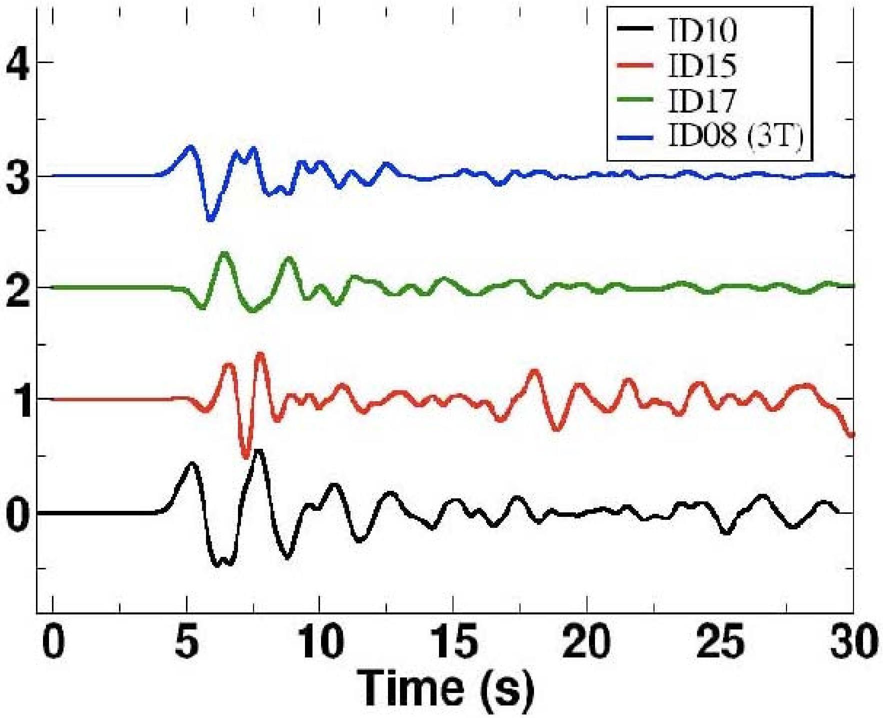
2 hypothetical strong events

- S1, S2 (M=6)
- Extrapolation from W1, W2
- Source : imposed geometry and kinematics

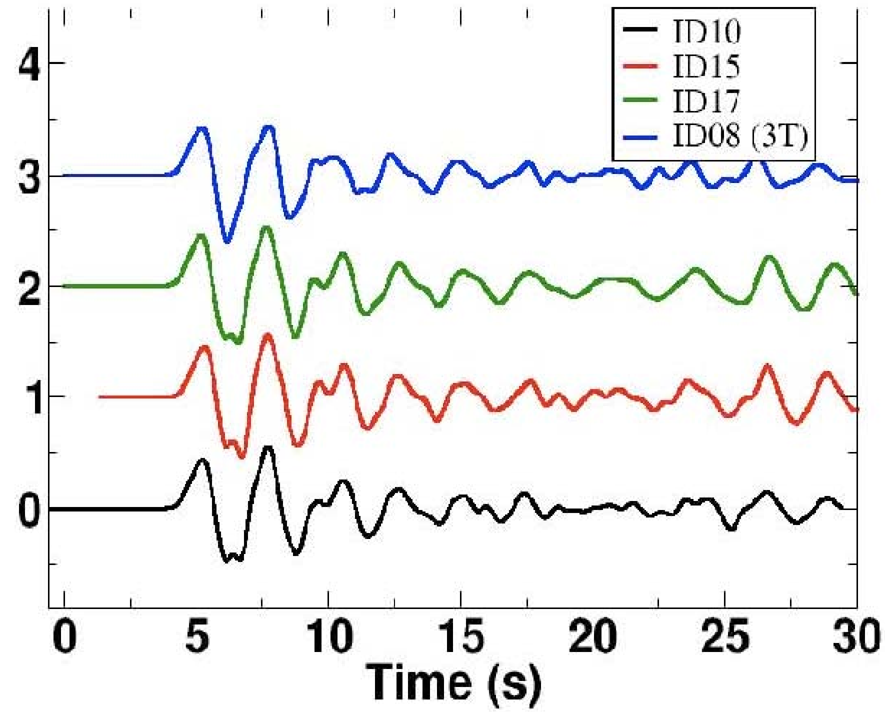


Iteration process : 3 teams (/6)

September 1, 2006



April 8, 2007



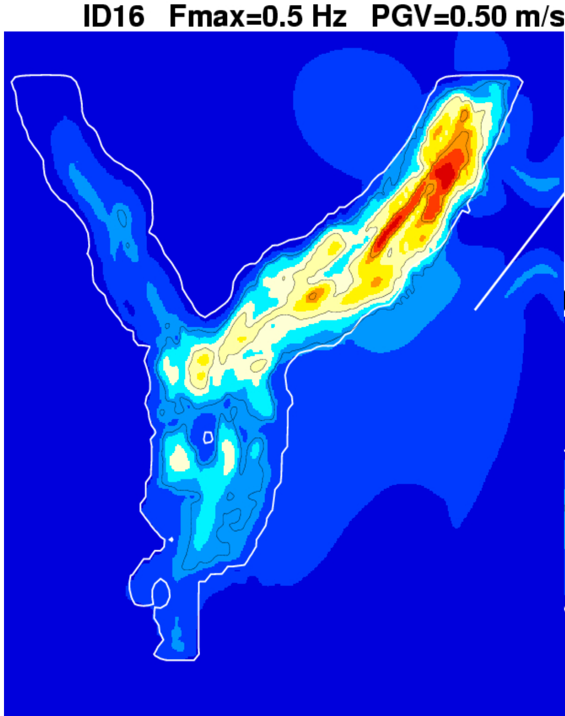
ID15 : bug in basin model definition

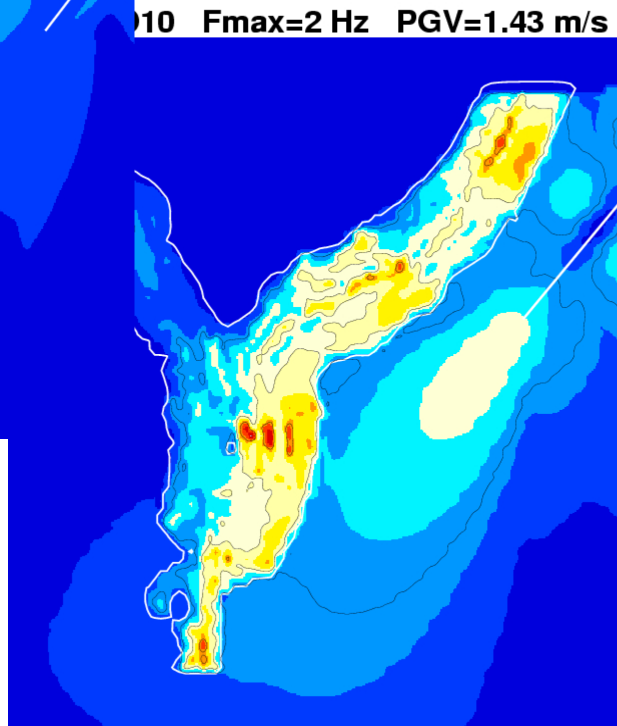
ID17 : bug in extended source definition

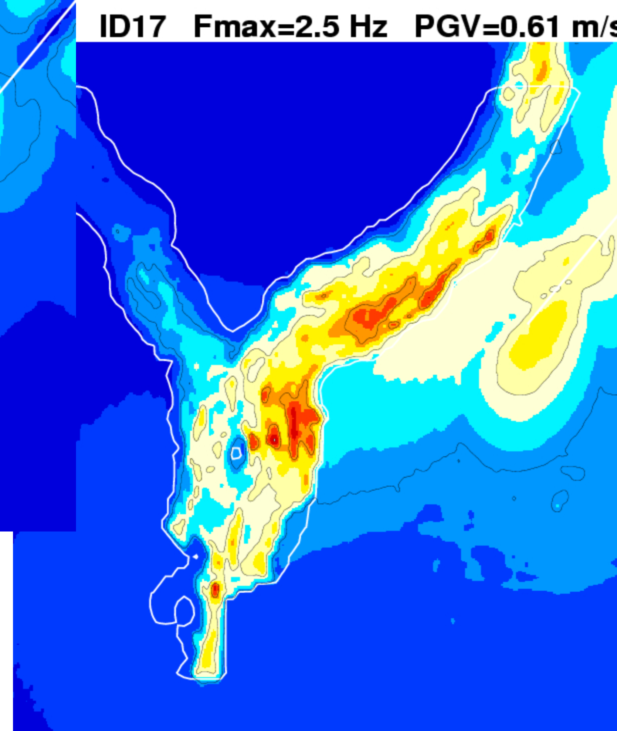
ID08 : bug in extended source definition

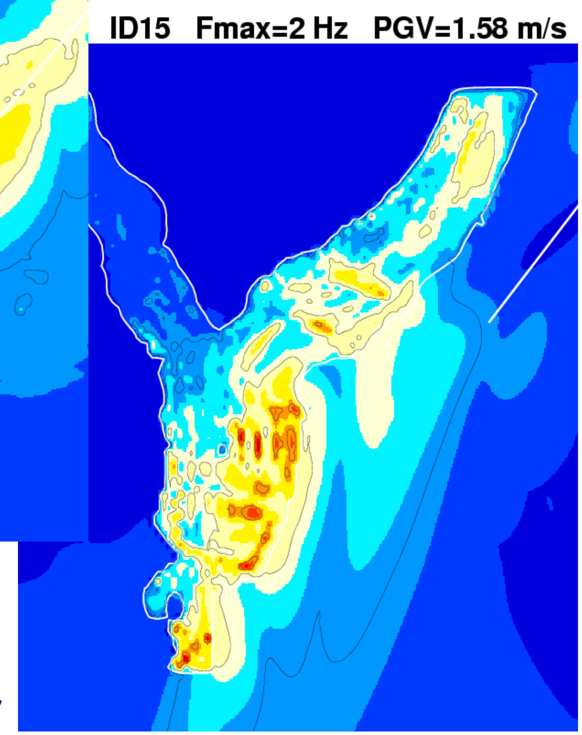
PGV maps, S1 case

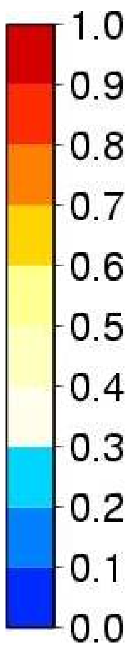
Initial predictions (3D, Flat)







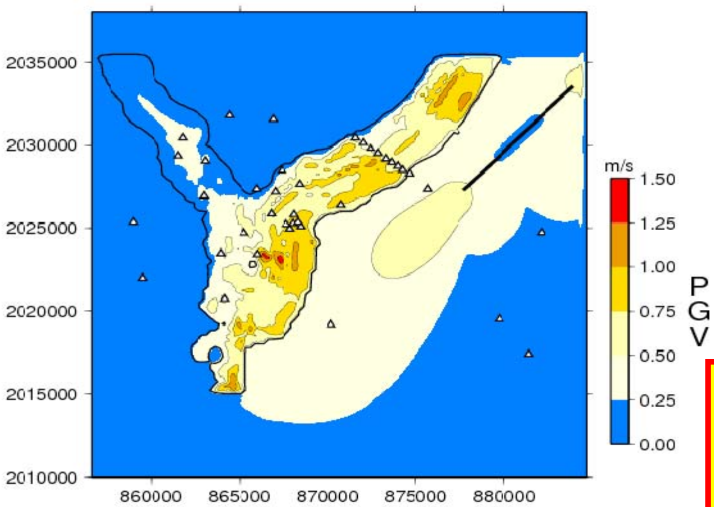




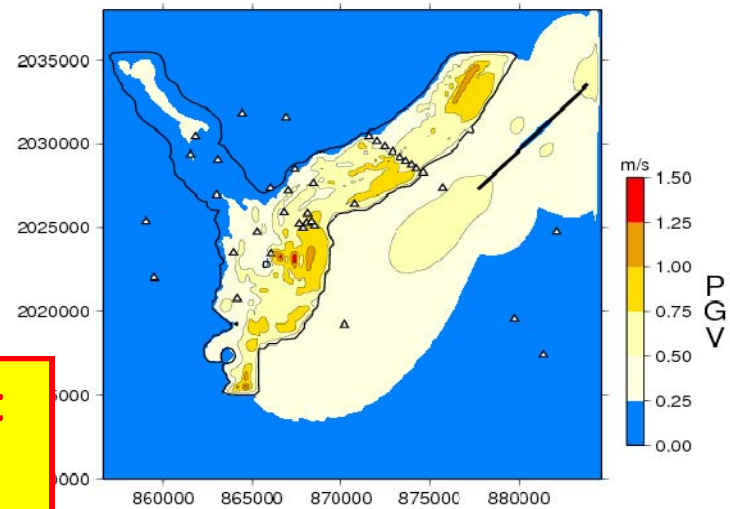
PGV maps from 3D predictions, flat case

After iteration

SEM1



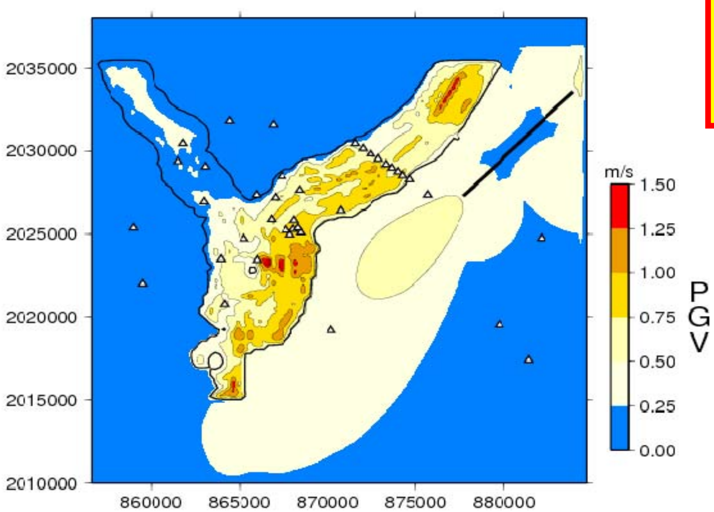
SEM2



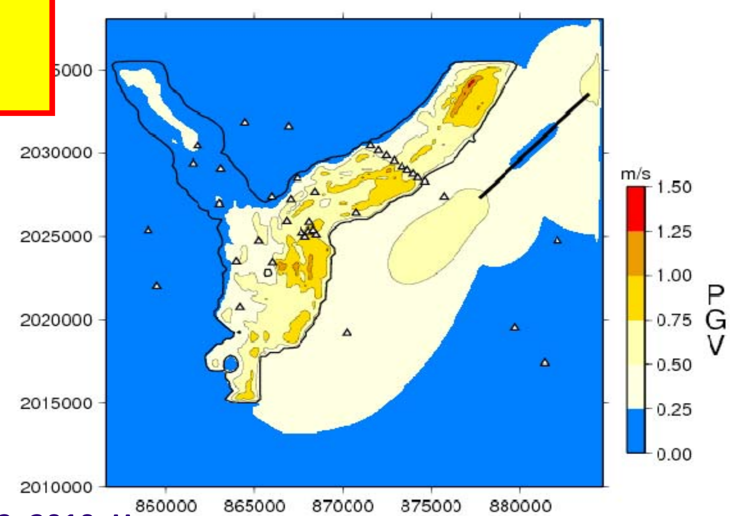
Very good agreement between global patterns

And peak values

FDM



DGM



Lessons from Verification tests in Europe

3D

- numerical simulation of ground motion is not yet a ”press-button” procedure,
- Good match up to 4 Hz obtained between various simulation techniques indicates a very encouraging level of maturity.
  - teams and codes who already compared their results are more likely to provide satisfactory results at the first iteration
- Emphasis on the importance of
  - the actual implementation of damping
  - the details of the discretization process for interfaces with large impedance contrast

»

1D/2D NL : not yet mature, ongoing

- Usefulness of preliminary checks on 2D L
- Key importance of damping in NL models
  - classical "Seed like" curves yield strong NL effects at least in deep deposits
  - ? Large effects at high frequencies because of damping ?

Outline

Introduction

Techniques for hazard zonation

Learning from examples :

- Mexico City
- Tehran
- Nice

Instructive Examples

A success story : Mexico City

- Simple, empirically based
- Supported by extensive background studies

A failure story : Tehran

- insufficiency of shallow information
- failure of H/V approach

An intermediate story : Nice

- Local hazard : Inconsistency between different approaches
- Consistency issues between hazard and vulnerability studies

Example 1 : Mexico (courtesy M. Ordaz, IdI, UNAM)

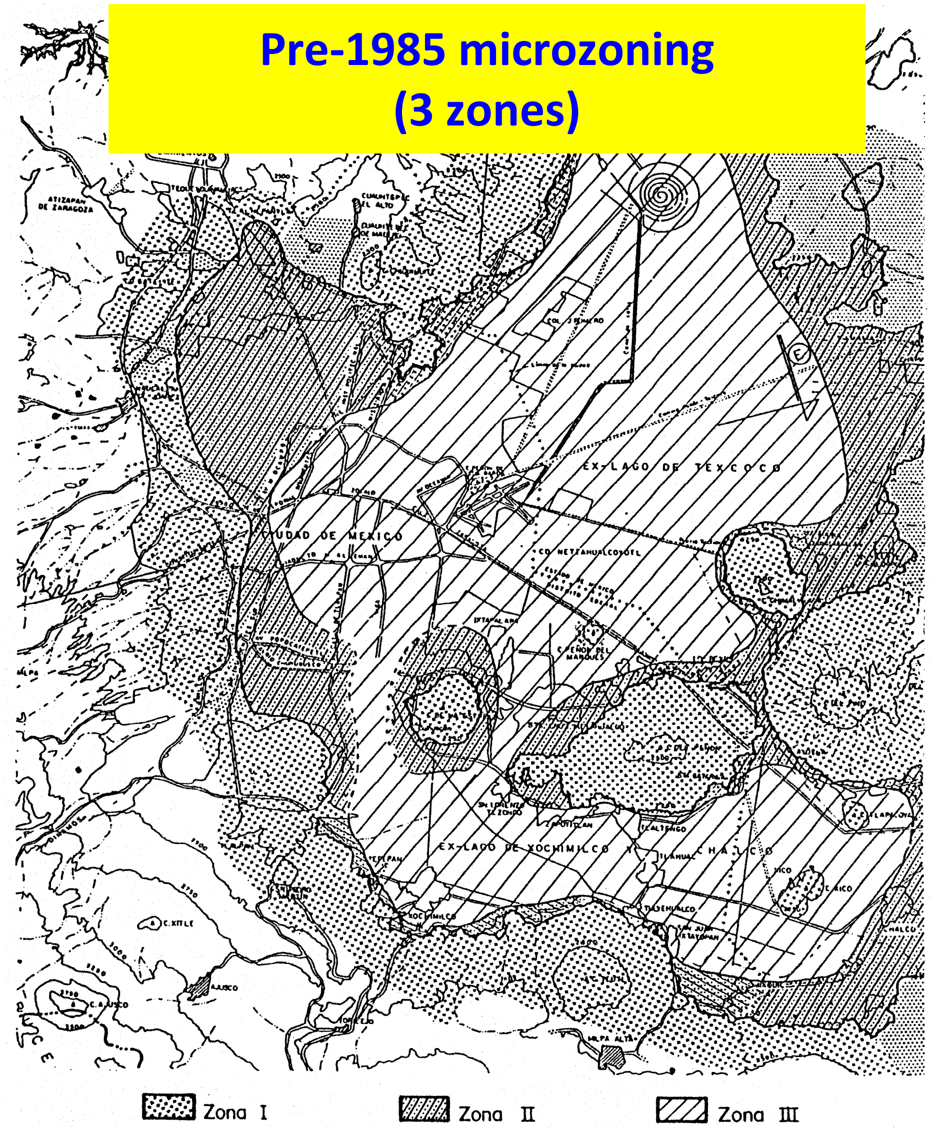
The "ideal" example :

A lot of advanced numerical and instrumental studies,

well assimilated and integrated through a simple relationship between

Sa and T_0,

allowing a straightforward estimation



Post 1985 studies in Mexico City

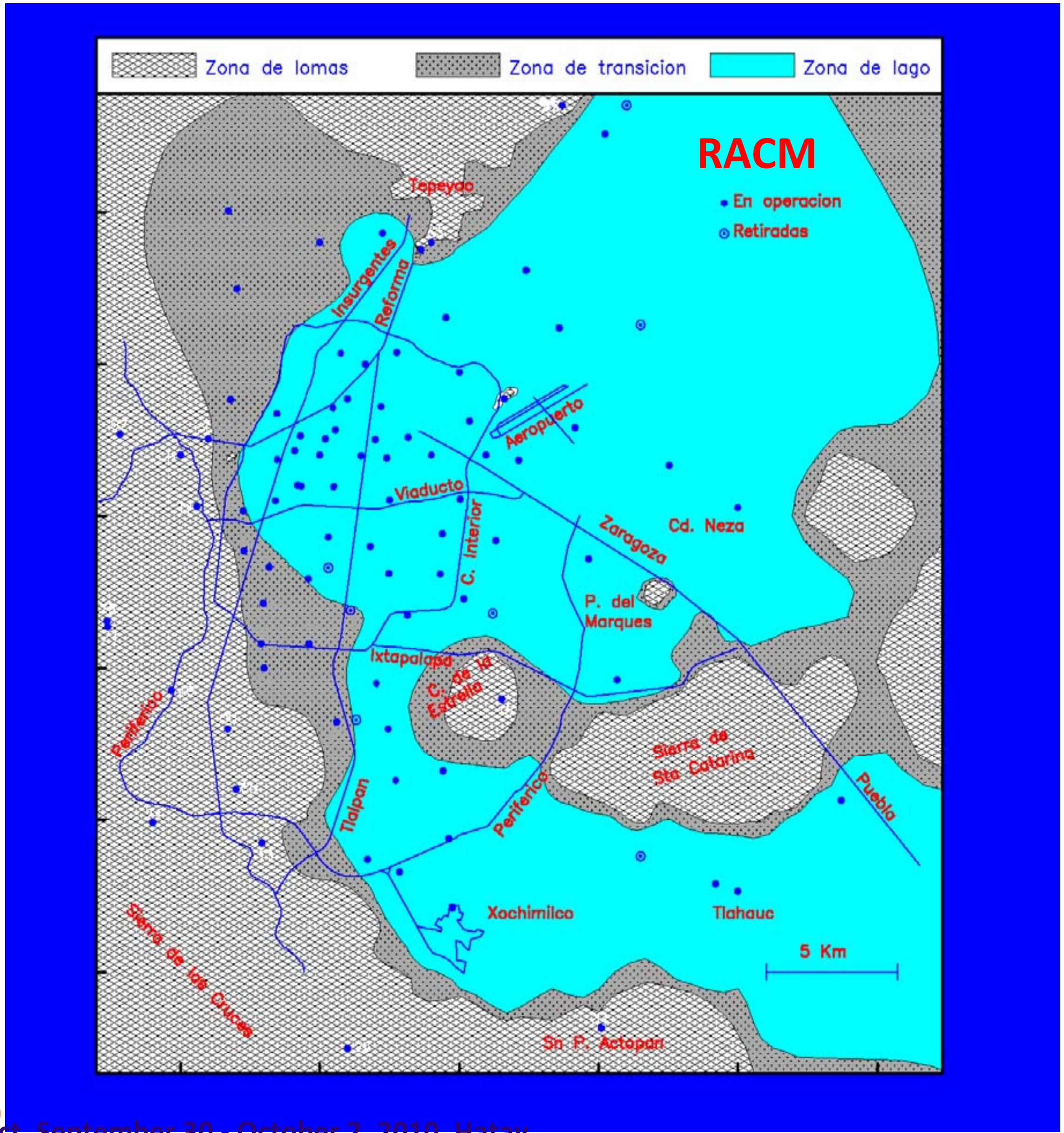
Numerous microtremor measurements were performed.

The RACM (Mexico City accelerometric network) was installed and allowed to gather many recordings

Many theoretical response models were constructed.

High intensity zones were indirectly identified from observed damage.

Geotechnical information systems of the city were highly improved.

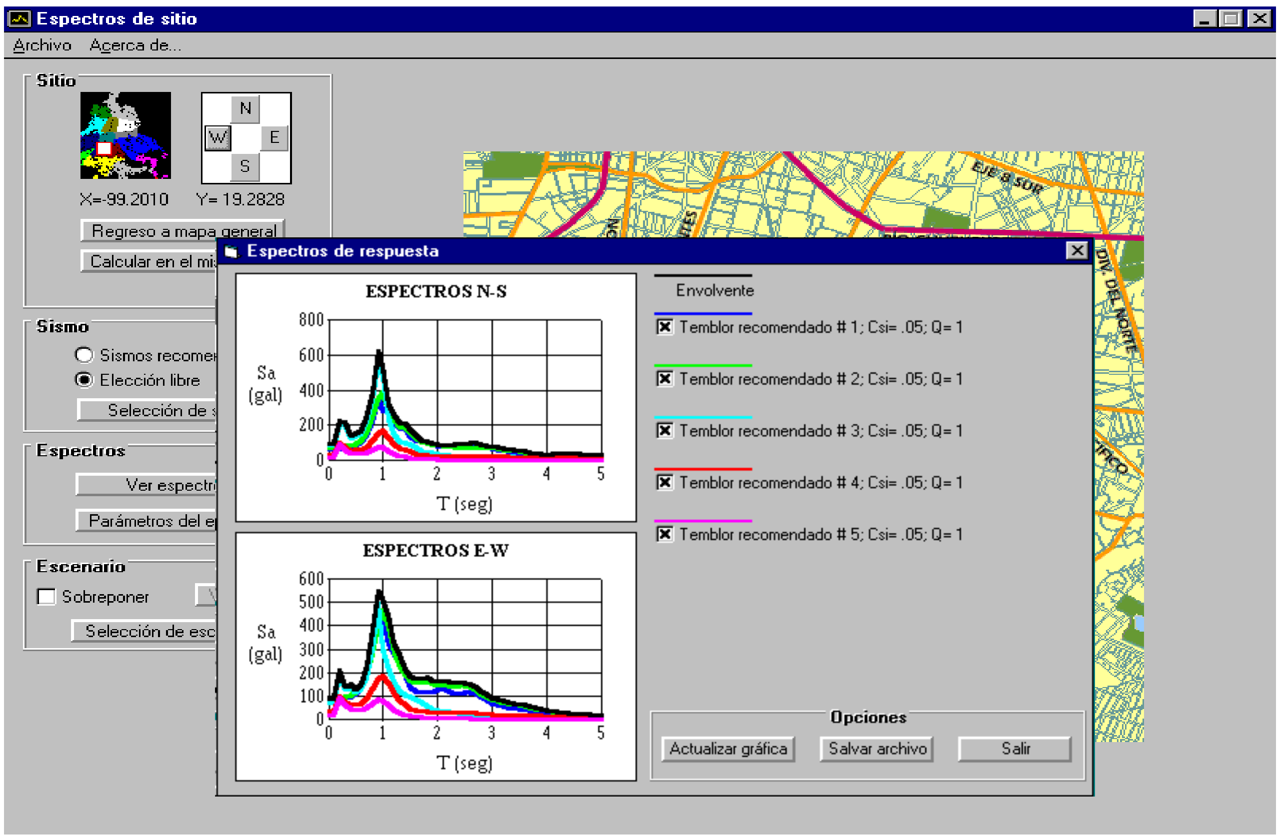


(After Ordaz, 2001)

Post 1985 studies in Mexico City

The ability to estimate ground motions was highly improved (thanks to RACM)

(physically driven interpolation of measured amplification, combined with UHS spectra, and quasi absence of NL phenomena)

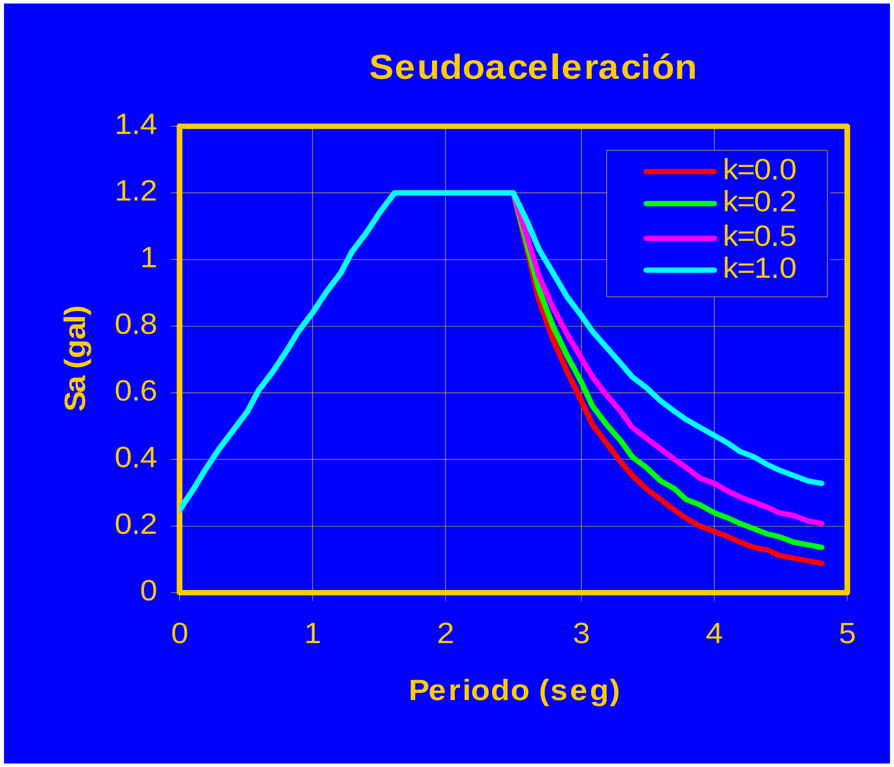


(After Ordaz, 2001)

Final recommendations

For each site, site specific pseudo-acceleration elastic spectra could be computed, associated to constant return period (uniform-hazard spectra),

And parameterized with 5 parameters a_0, c, T_a, T_b , k,



$$a = \begin{cases} a_0 + (\beta c - a_0)\dfrac{T}{T_a}; & si \quad 0 \le T < T_a \\ \beta c; & si \quad T_a \le T < T_b \\ \beta c p \left(\dfrac{T_b}{T}\right)^2; & si \quad T \ge T_b \end{cases}$$

$$p = k + (1-k)\left(\frac{T_b}{T}\right)^2$$

(After Ordaz, 2001)

Relationships between coefficients and T_s

$$a_o = \begin{cases} 0.1 + 0.15(T_s - 0.5); & \text{si } 0.5 \le T_s \le 1.5 \text{ s} \\ 0.25; & \text{si } T_s > 1.5 \text{ s} \end{cases}$$

$$T_a = \begin{cases} 0.2 + 0.65(T_s - 0.5); & \text{si } 0.5 < T_s \le 2.5 \text{ s} \\ 1.5; & \text{si } 2.5 < T_s \le 3.25 \text{ s} \\ 4.75 - T_s; & \text{si } 3.25 < T_s \le 3.9 \text{ s} \\ 0.85; & \text{si } T_s > 3.9 \text{ s} \end{cases}$$

$$c = \begin{cases} 0.28 + 0.92(T_s - 0.5); & \text{si } 0.5 < T_s \le 1.5 \text{ s} \\ 1.2; & \text{si } 1.5 < T_s \le 2.5 \text{ s} \\ 1.2 - 0.5(T_s - 2.5); & \text{si } 2.5 < T_s \le 3.5 \text{ s} \\ 0.7; & \text{si } T_s > 3.5 \text{ s} \end{cases}$$

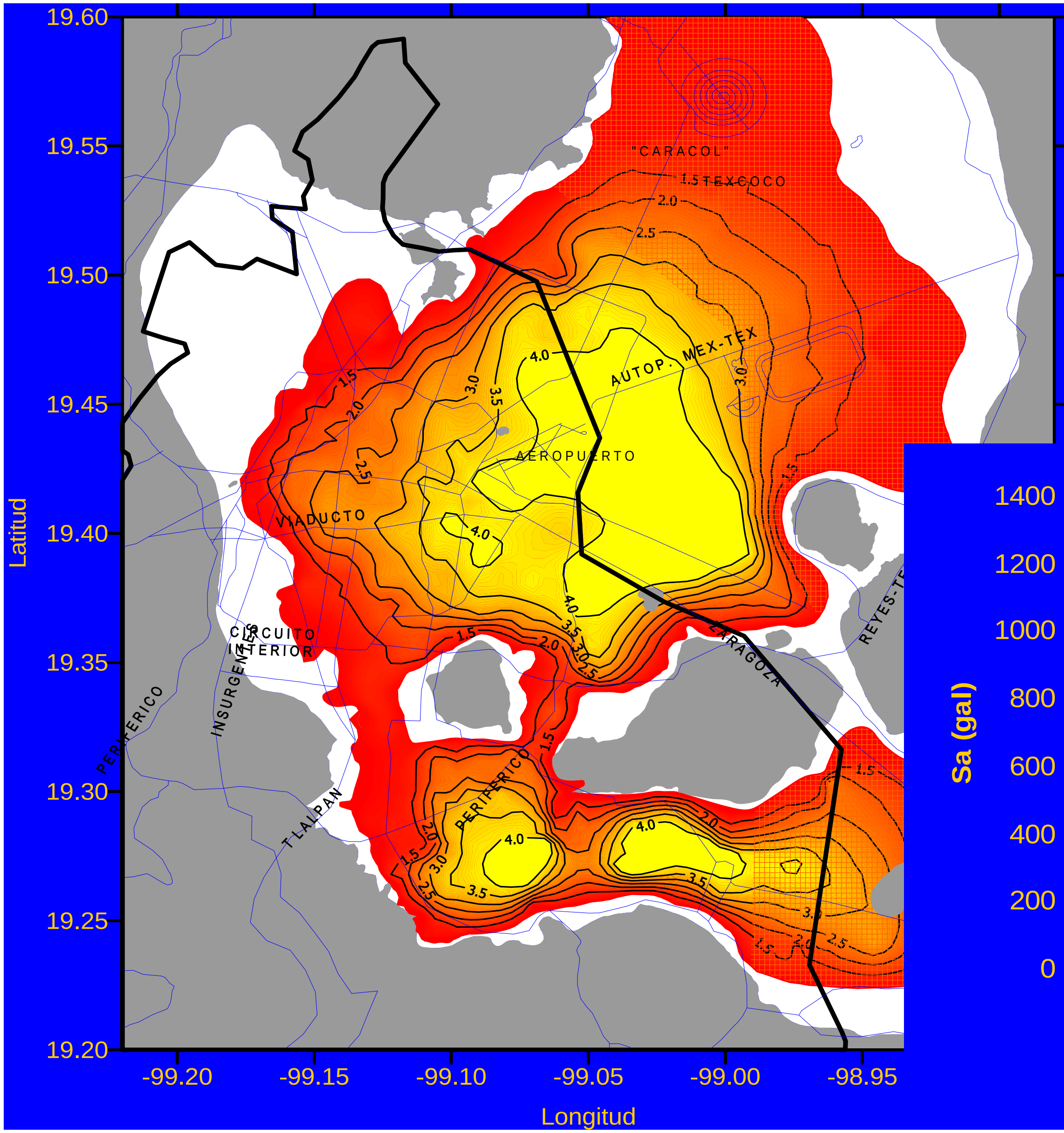
$$T_b = \begin{cases} 1.35; & \text{si } T_s \le 1.125 \text{ s} \\ 1.2\, T_s; & \text{si } 1.125 < T_s \le 3.5 \text{ s} \\ 4.2; & \text{si } T_s > 3.5 \text{ s} \end{cases}$$

$$k = \begin{cases} 2 - T_s; & si \;\; 0.5 < T_s \le 1.65 s \\ 0.35; & si \;\; \mathrm{T_s} > 1.65\text{s} \end{cases}$$

Based mainly on instrumental recordings

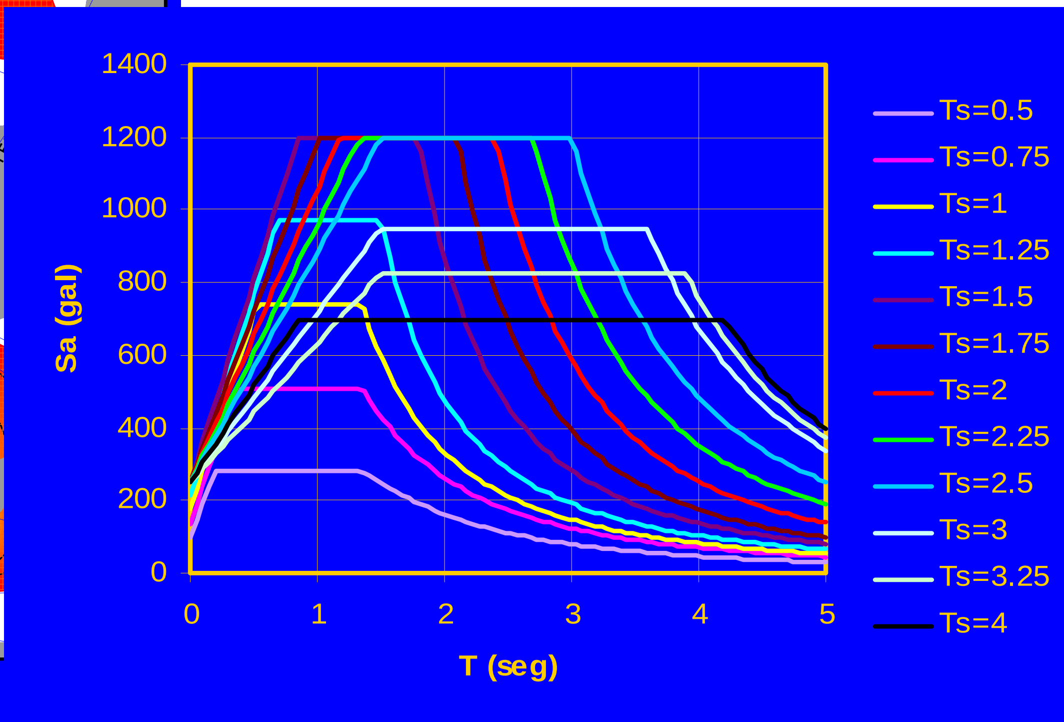
(After Ordaz, 2001)

Map of ground periods



Importance of site period !

Elastic spectra



(After Ordaz, 2001)

Example #2 : Tehran

12 Mhab

Major faults in the immediate vicinity

- North-Tehran : M > 7
- South and East : M > 6 ?

Strong historical events

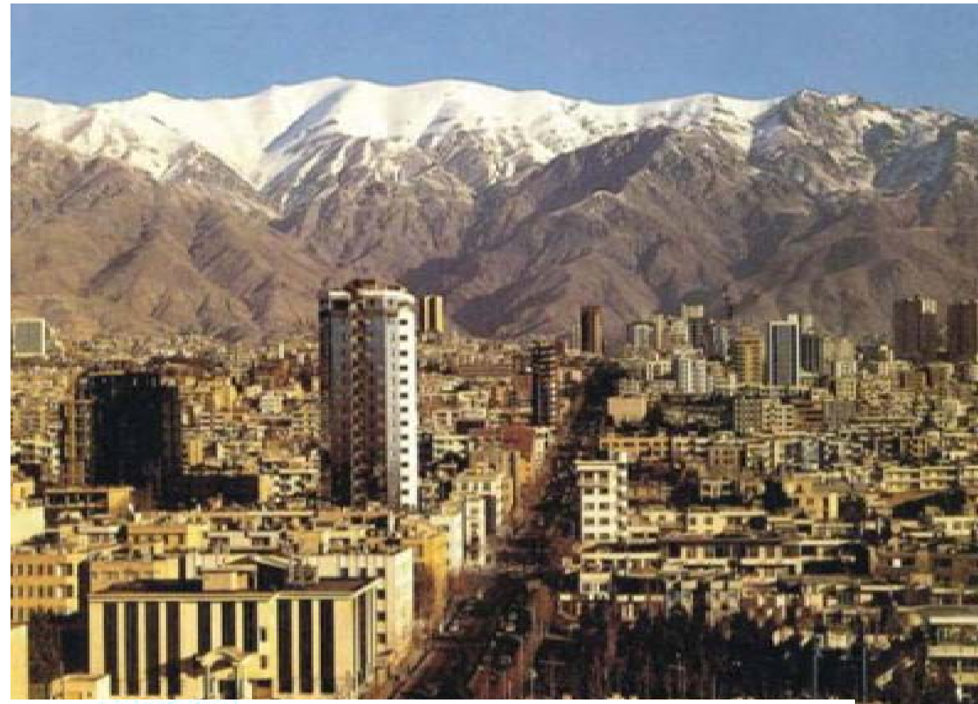
- but no recent local event

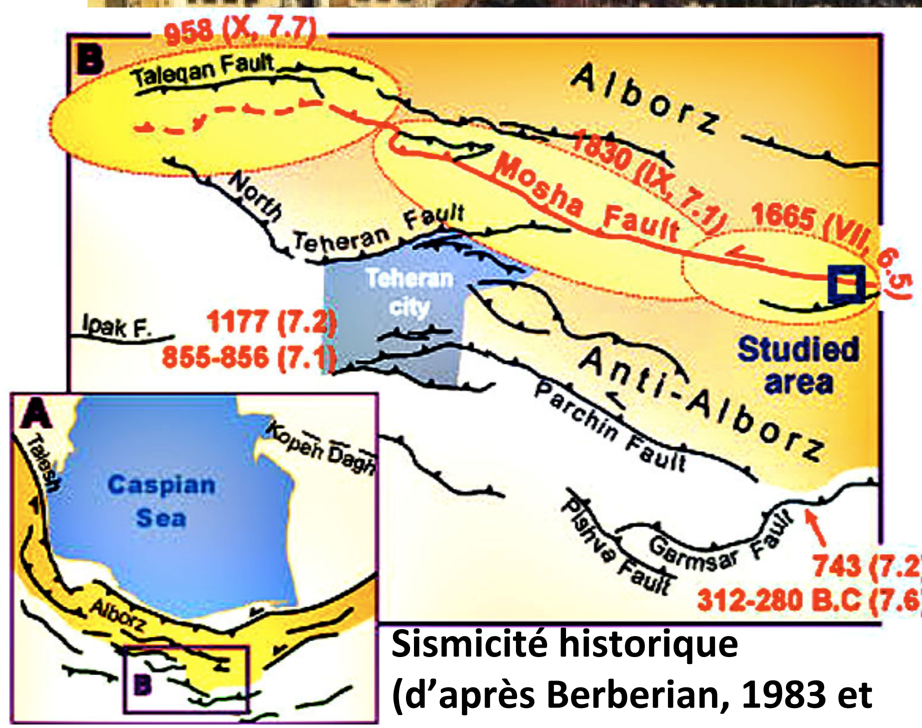
Rapid (poorly controled) urban development

An up-to-date building code

- ? Suitable for Tehran site
- ? Enforcement

(After Haghshenas, 2005)





Sismicité historique (d'après Berberian, 1983 et Berberian & Yeats, 1999)

Microzonation and site effect studies in Tehran

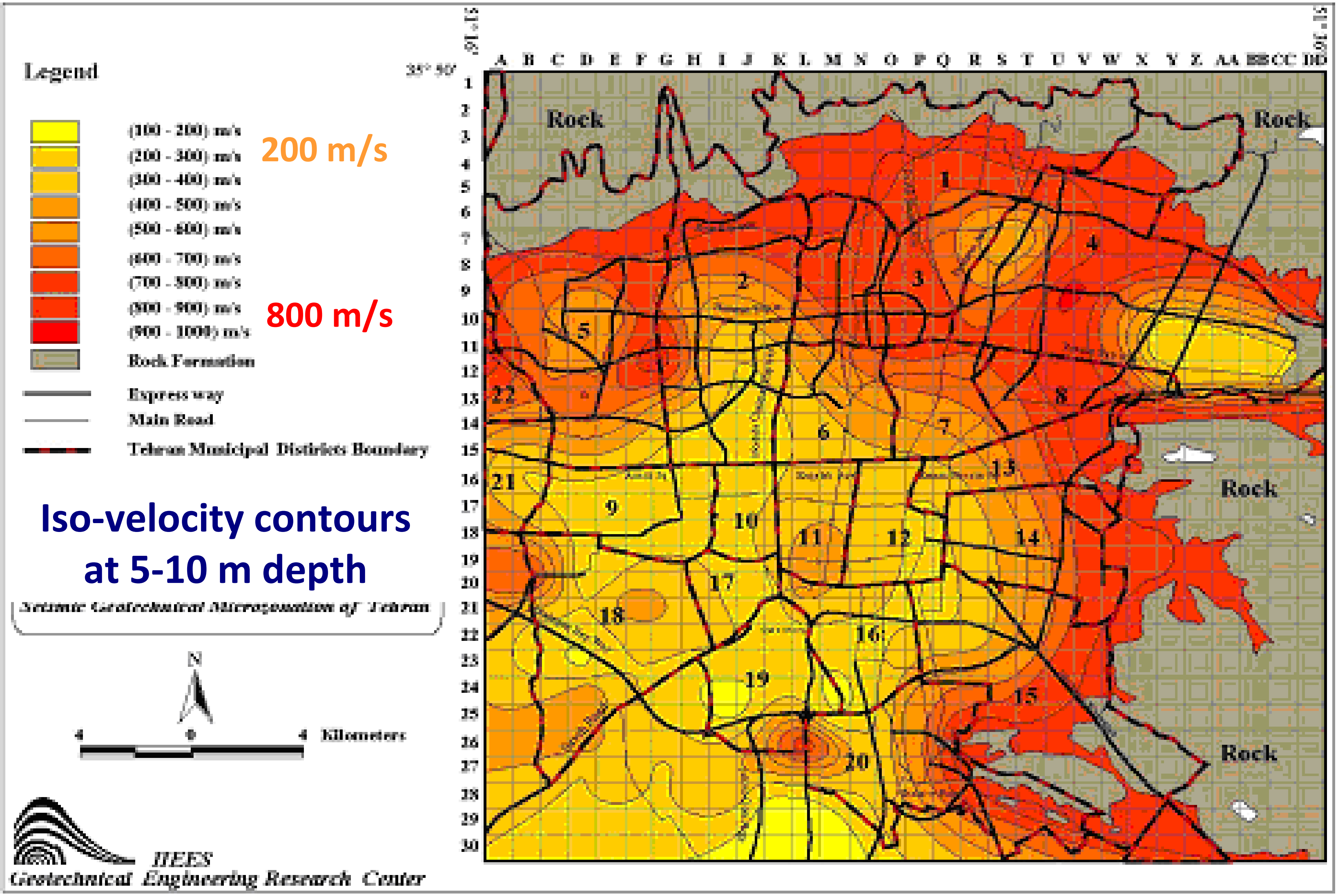
- Previous studies :
  - Geotechnical microzonation : IIEES (since 1994 : south then north)
  - Seismic "microzonation" (scenario) : JICA + CEST, 2001

- Contents
  - Gathering of existing geological & geotechnical information
  - Acquisition of additional data
    - Geophysics, borings, sampling, lab tests
  - Microtremor measurements + H/V processing
  - 1D modelling (SHAKE type)

- Results concerning site effects
  - Stiff and "shallow" deposits in the North
  - Softer and thicker deposits in the South
  - Moderate amplification (<2) only at intermediate and high frequencies (f>1-2 Hz)

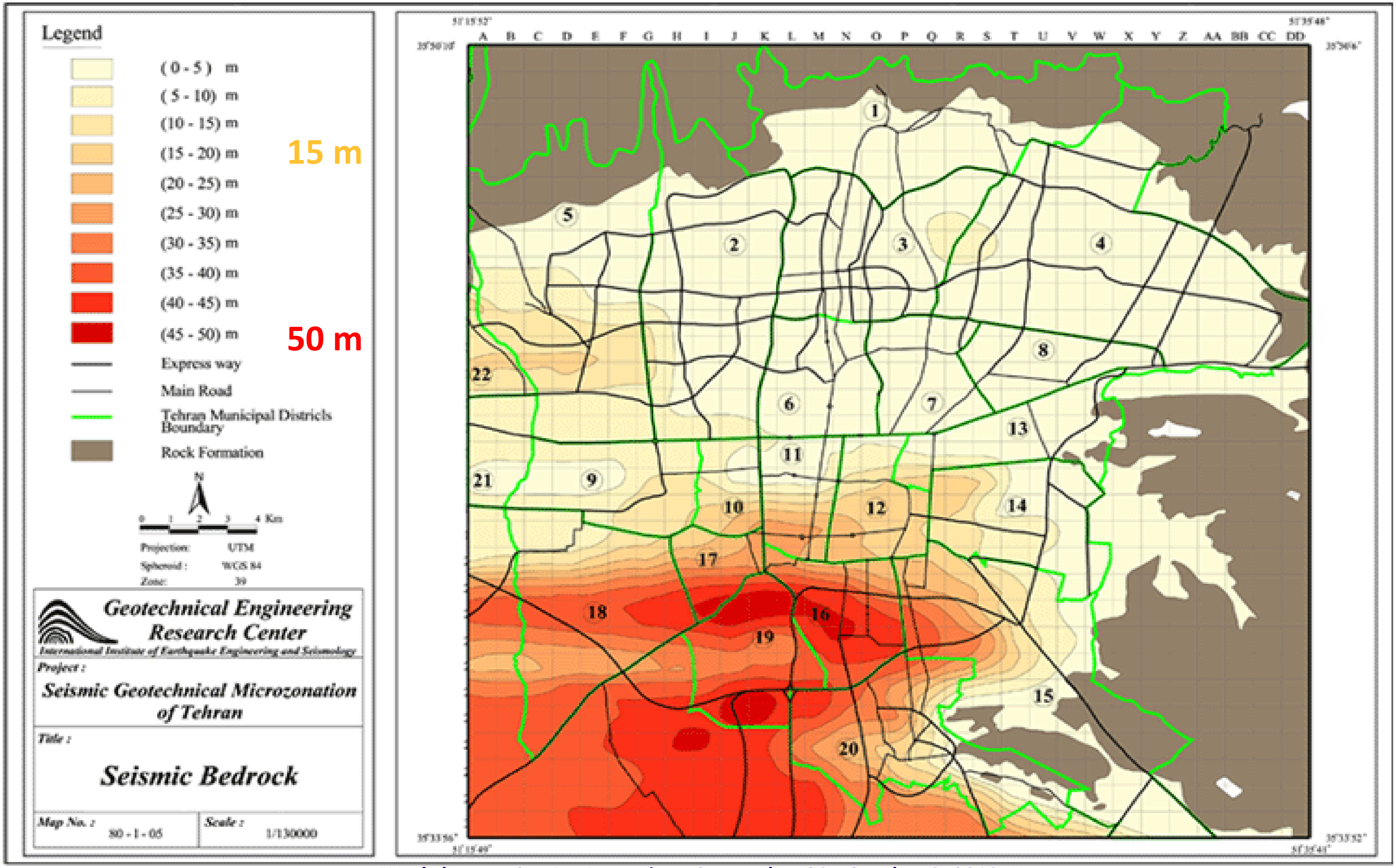
Normal to stiff shallow deposits (IIEES)

(After Haghshenas, 2005)



A SHALLOW "SEISMIC BEDROCK" [IIEES, Vs > 600-700 m/s]

(After Haghshenas, 2005)



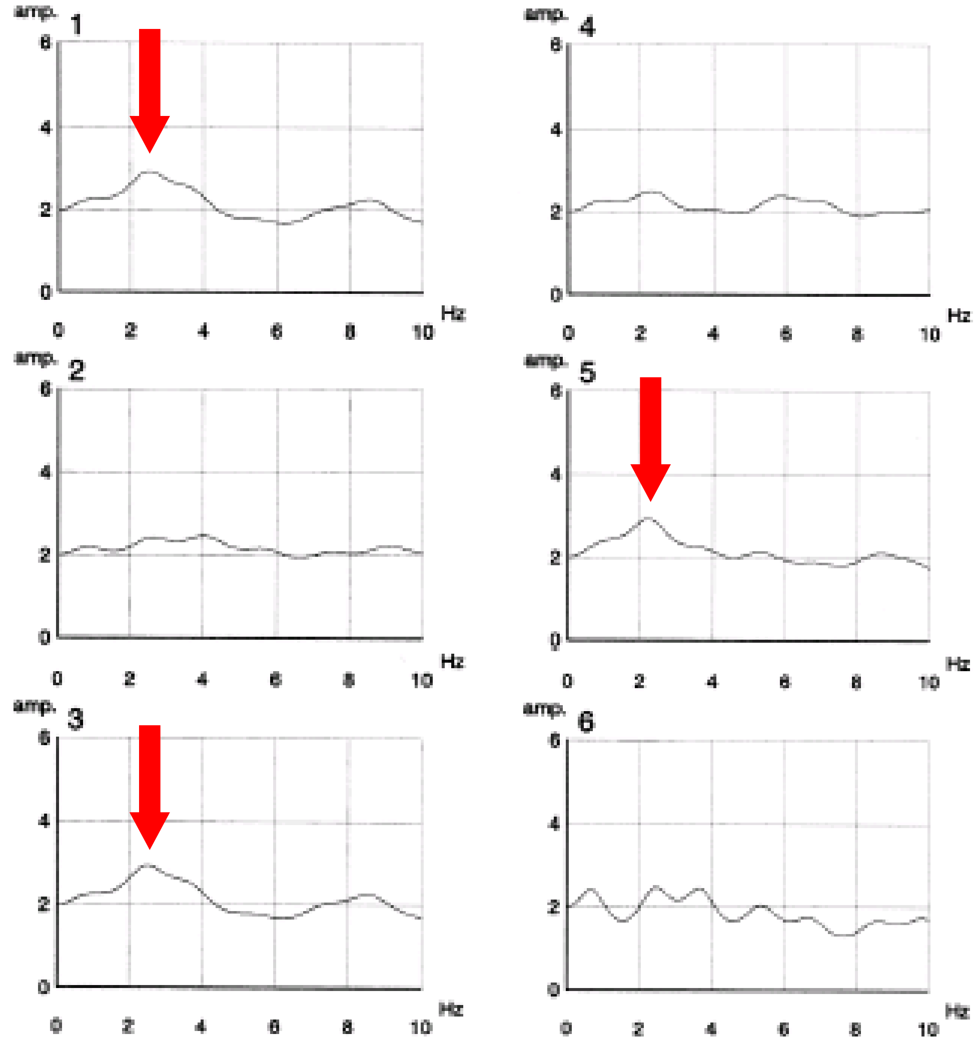
Example 1D Fourier transfer functions estimated from shallow velocity structure (V_{S30})

Medium to stiff, shallow deposits

(South : V_{S30} > 200 m/s,

North : V_{S30} > 400 m/s)

Intermediate to high frequency, moderate amplification



(After **JICA & CEST, 2001)**

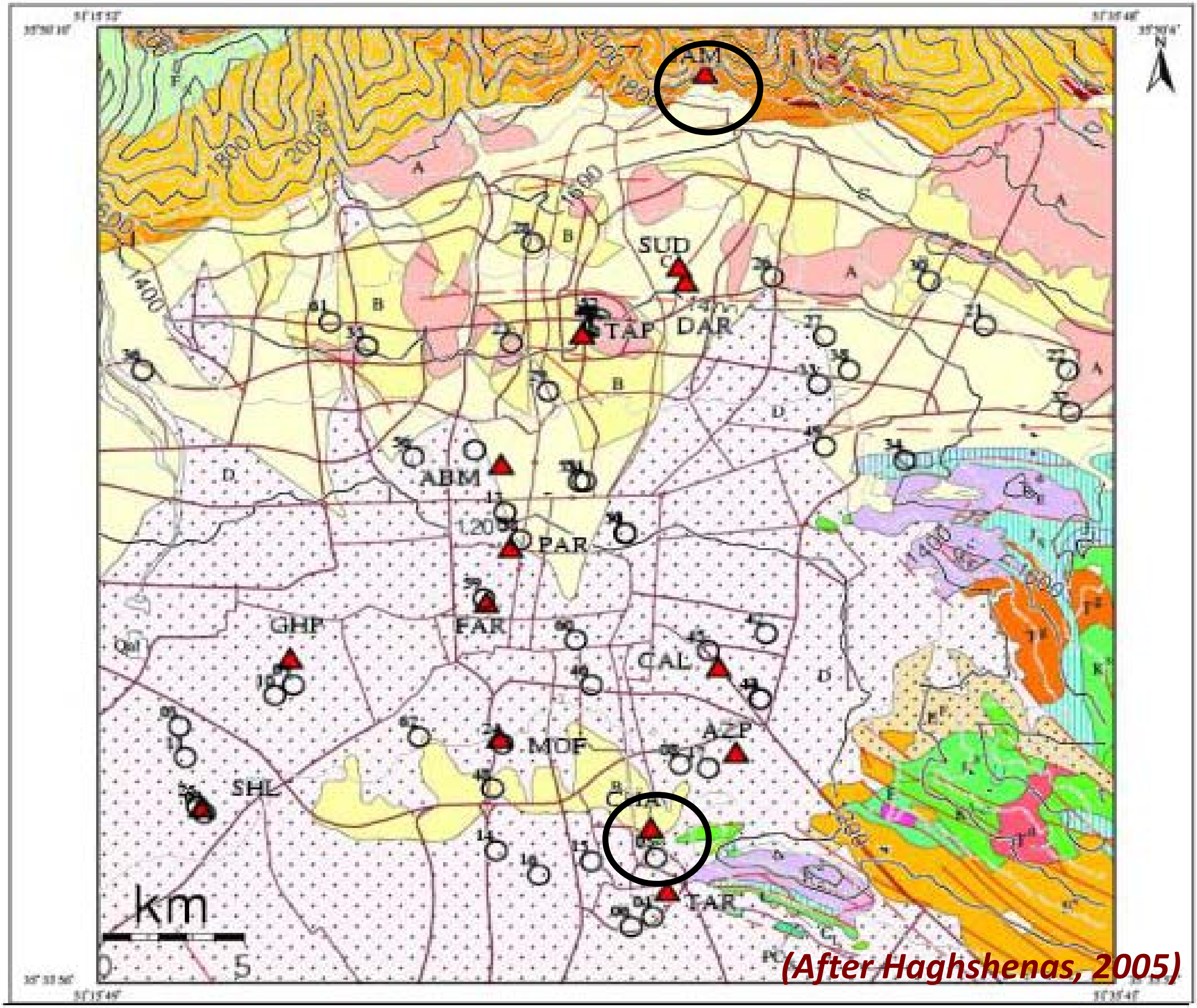
"Ground truth" = seismological recordings

Temporary field survey

▲ **13 temporary instruments, continuous recording (5 months, 10 CMG40, 3 L22, 13 CMG5)**

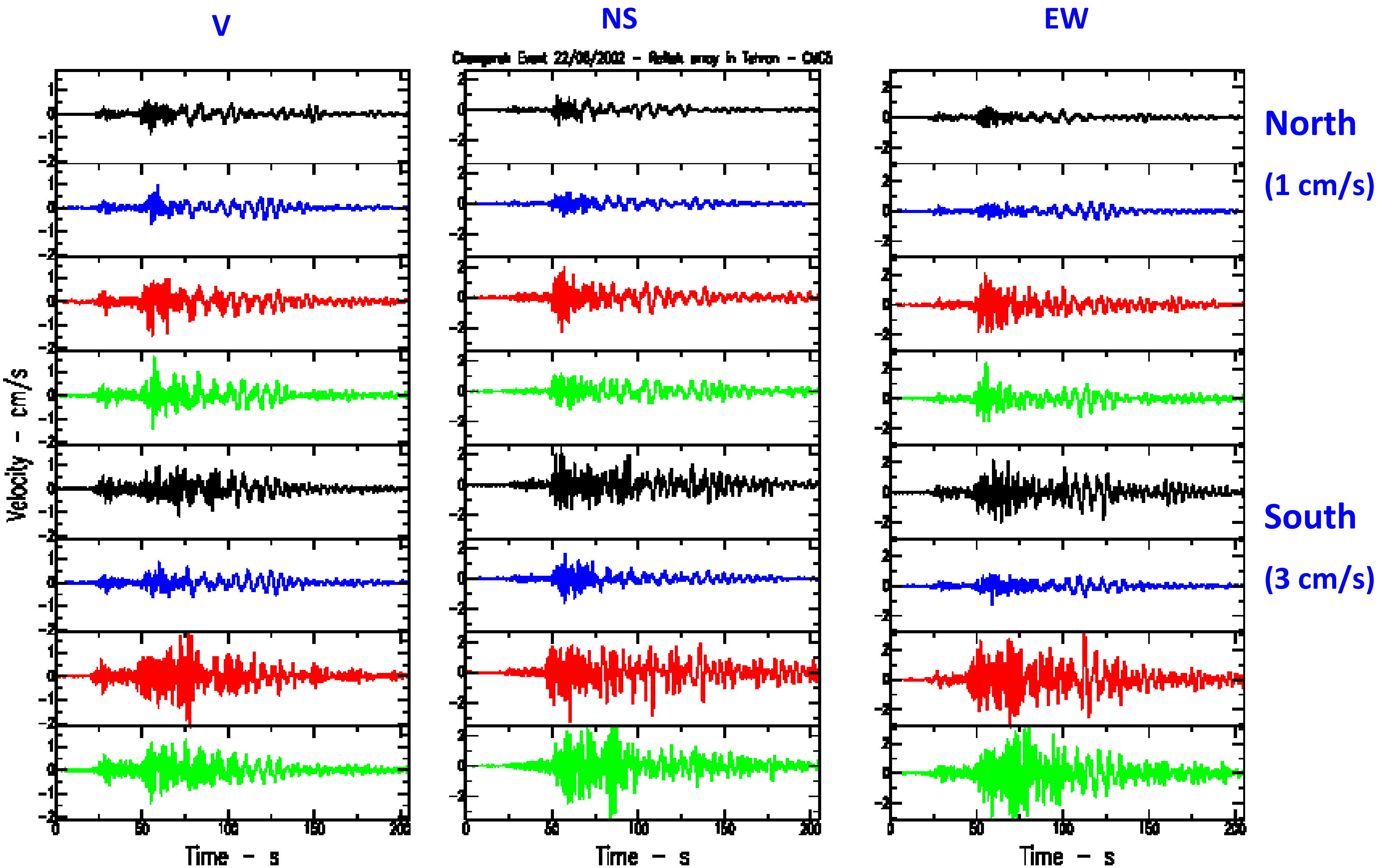
(2 on Rock)

○ **60 single point noise measurements**



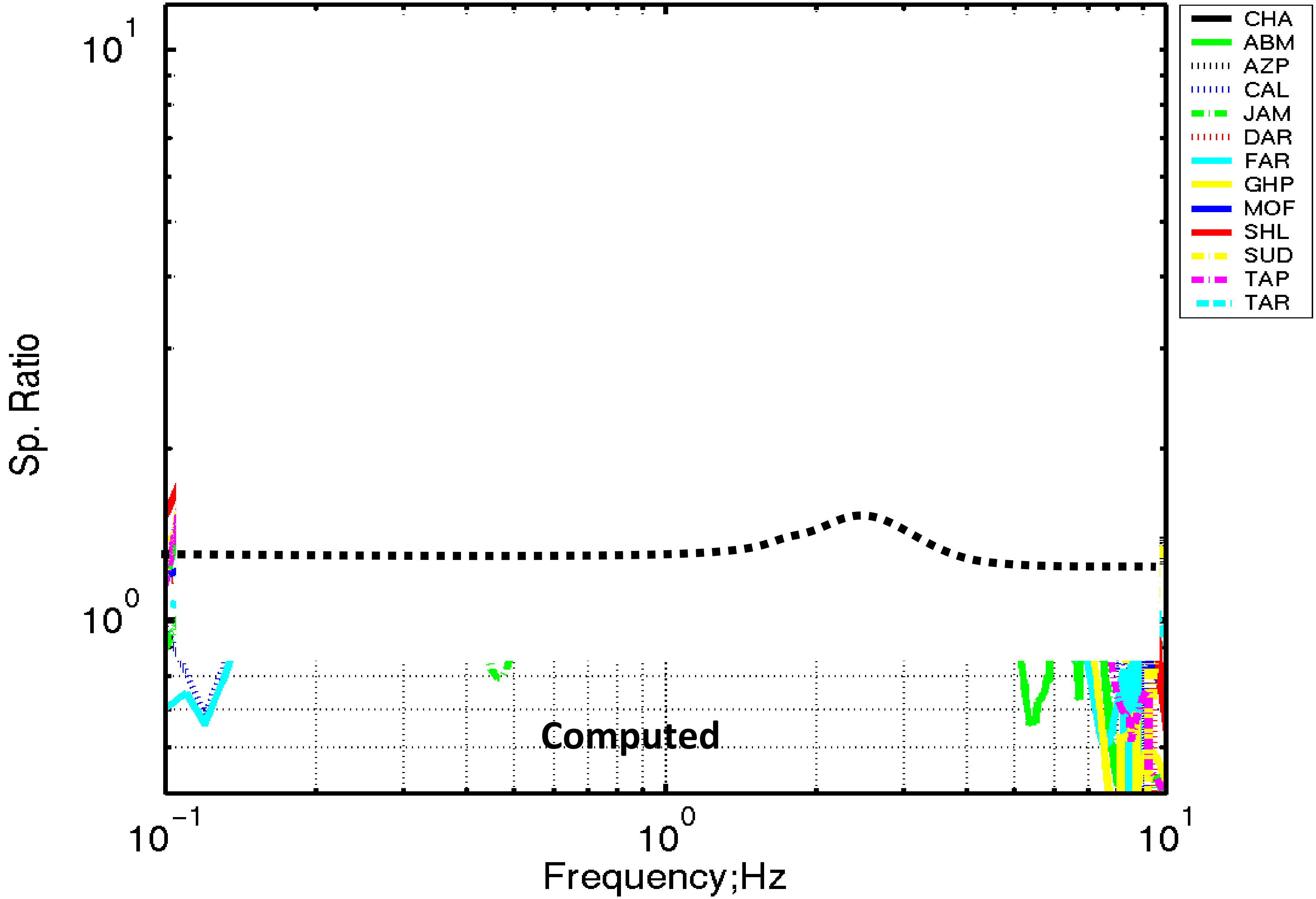
(After Haghshenas, 2005)

CHANGUREH EVENT, 22/06/2002 : VELOCITY TRACES in TEHRAN

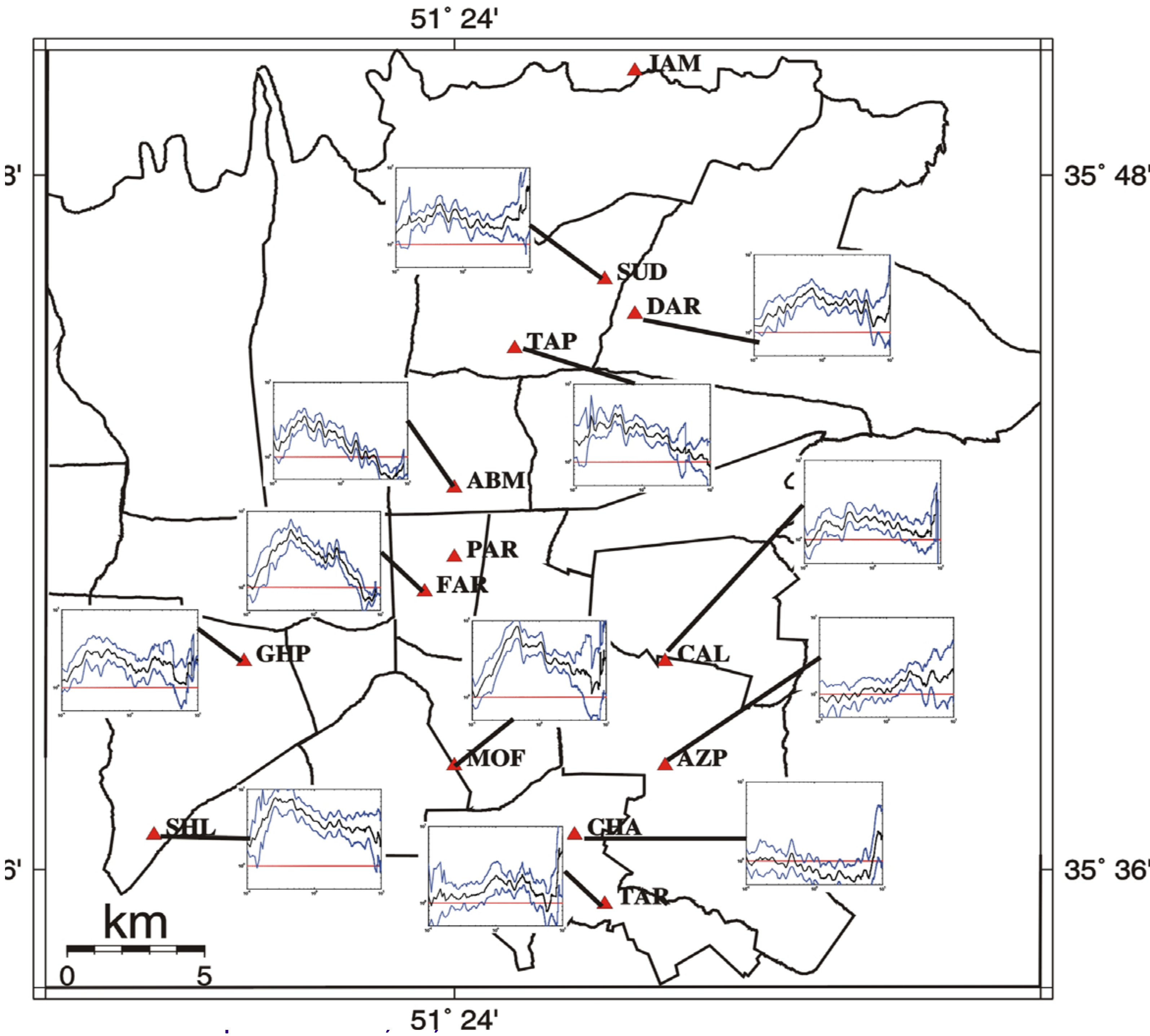


Comparison of measured / computed amplifications

(After Haghshenas, 2005)



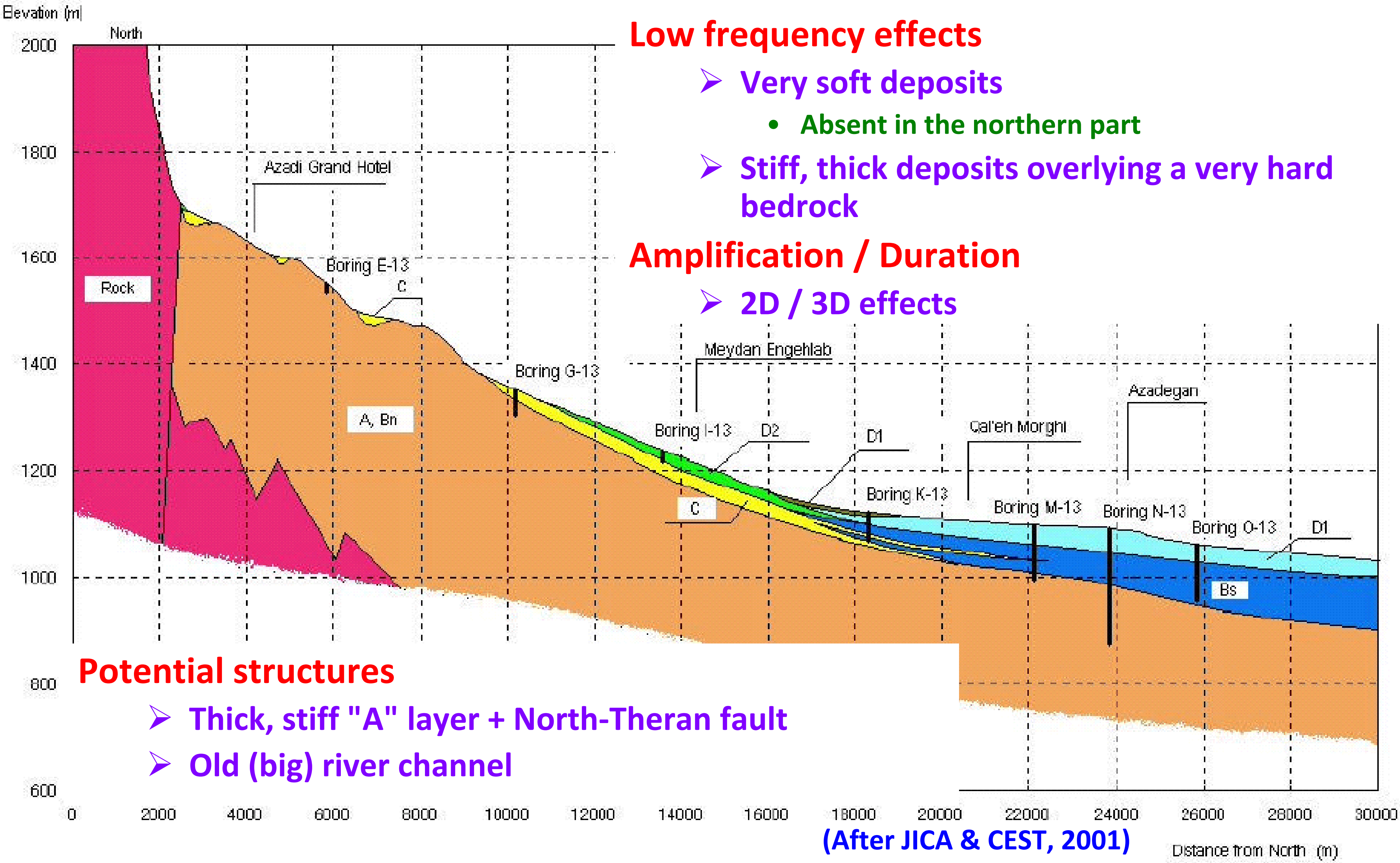
Tehran : observed amplifications



Increase from NE to SW

Broad-band everywhere, except in SE (TAR, AZP, CAL)

? Why such a discrepancy ?



Low frequency effects

- ➢ Very soft deposits
  - Absent in the northern part
- ➢ Stiff, thick deposits overlying a very hard bedrock

Amplification / Duration

- ➢ 2D / 3D effects

Potential structures

- ➢ Thick, stiff "A" layer + North-Theran fault
- ➢ Old (big) river channel

(After JICA & CEST, 2001)

Lessons from the Tehran case

Discrepancy Observations / "classical" engineering expectations

- Amplification : Broad band, large / slight, high frequency
- ? Origin
- ? Practical consequences for engineering (building design, urban planning)

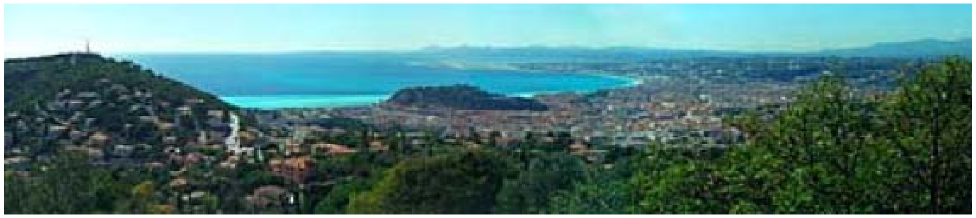
Numerical approach

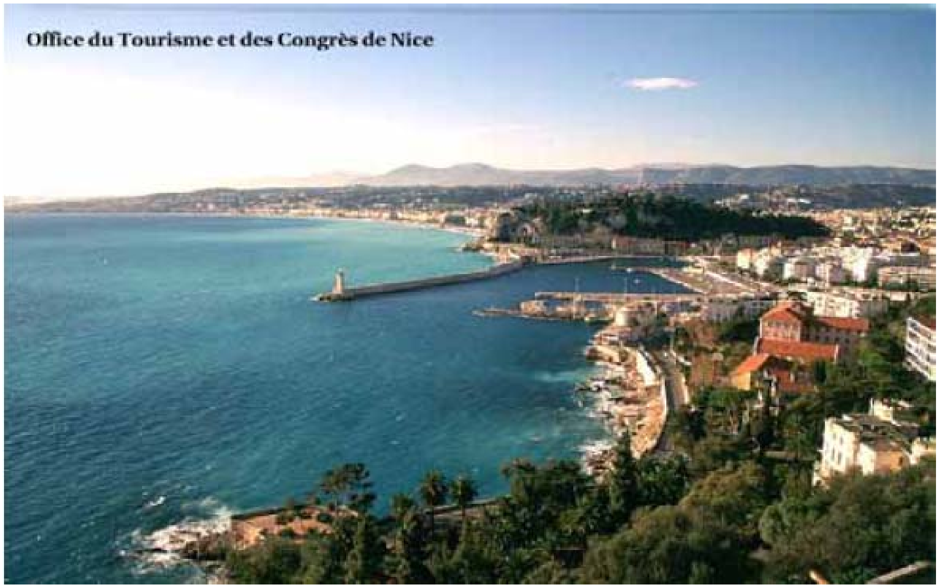
- Requires a good starting model (not only shallow V_{S30} !!!)
- Scale: from a few m à several km depth
  - detailed geotechnical data (~ OK)
  - "intermediate depth" geophysics" : MISSING
    - Impossibility to validate any physical interpretation

Instrumental approach

- Mandatory to calibrate and (in)validate the results of numerical modelling
- Uneasy to interpolate without any satifactory model
- Limitations of the microtremor classical H/V technique
  - Need for earthquake recordings within the city : easier with a sensitive, mobile network (lasts only a few monthes)

Example # 3 : Nice



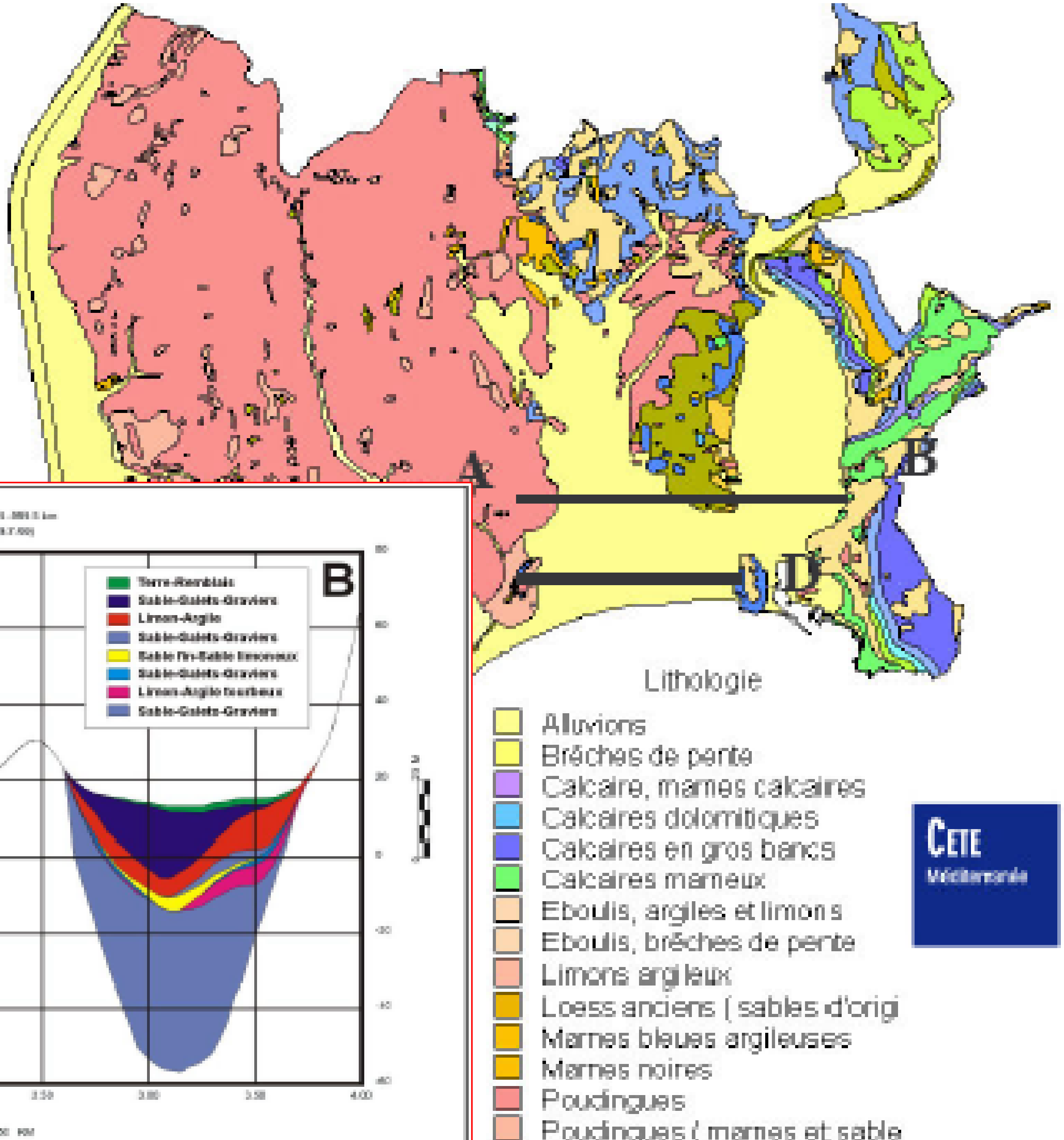


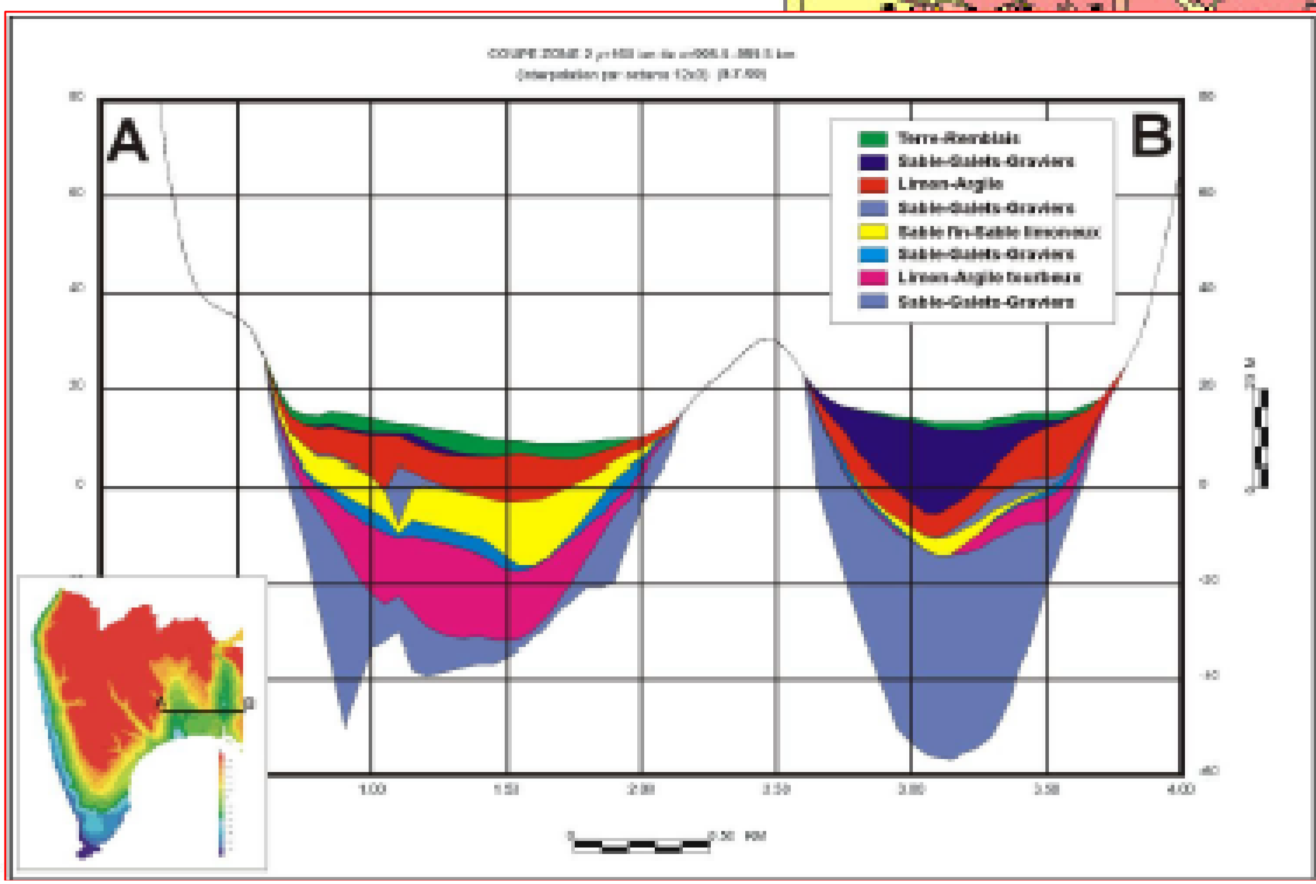
Nice

- **Background studies**
  - Permanent SM instrumentation + temporary WM experiments
  - Compilation of geotechnical data (borehole, ….) and 3D model
  - Extensive microtremor survey (H/V)
  - Building inventory and vulnerability assessment (typology based)
  - Building frequencies

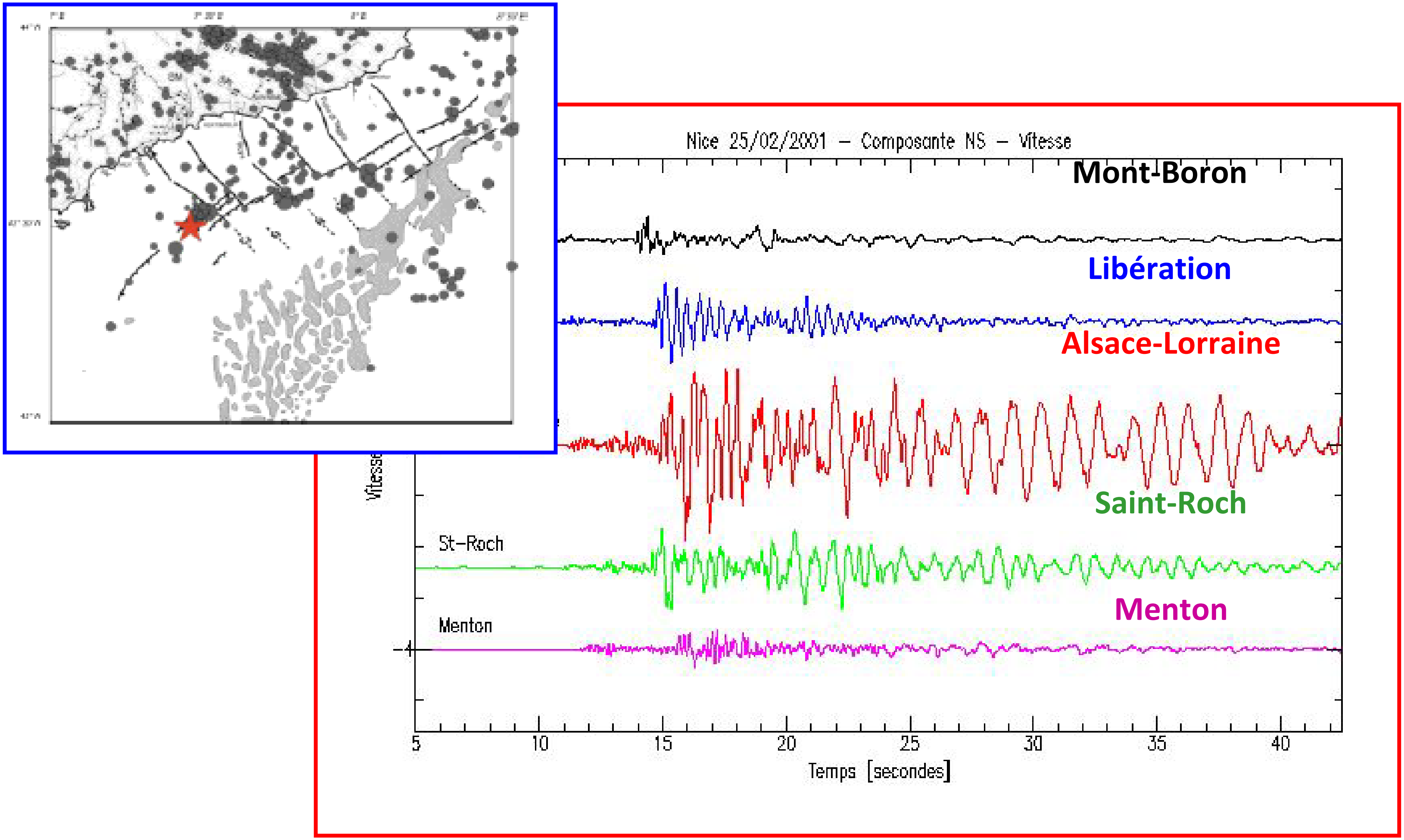
- **Ongoing "PPRS" study**
  - local building code
  - "expert" vulnerability assesement for important individual buildings + average "block" / area vulnerability assessment (vulnerability index)

Geotechnical model

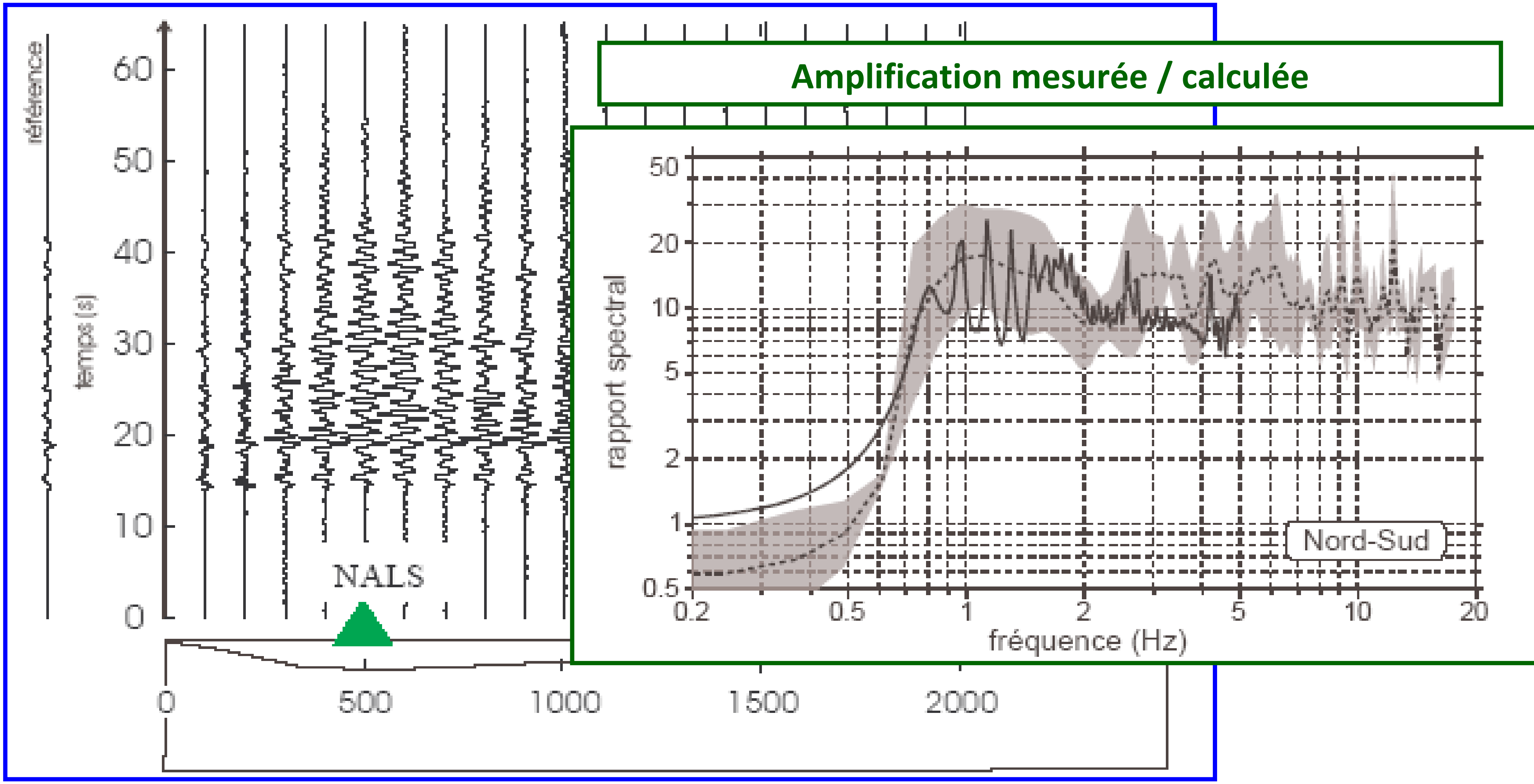




Example recordings from the local SM network : 25/02/2001



Example 2D computations and comparison with observations



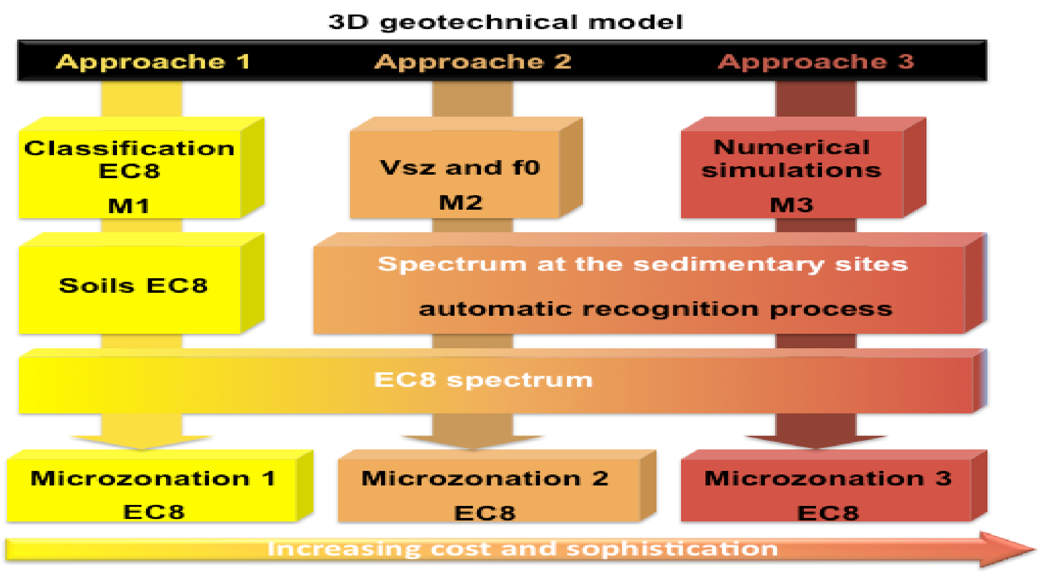
Coupe Est-Ouest

(M. Kham, J.-F. Semblat et al.)

Local hazard = Nice

- 3D detailed geotechnical model + 3 methods
  - EC8 / national rules (A -B - C - D - E)
  - empirical approach based on (f_0, V_{SZ}) - and KIKNET data
  - 1D computations and A-E spectra applied according to 1D results

- ? Which to choose ?



Courtesy A.-M. Duval et al., 2009

Local hazard = Nice

- 3D detailed geotechnical model + 3 methods
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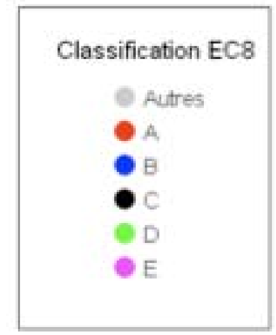
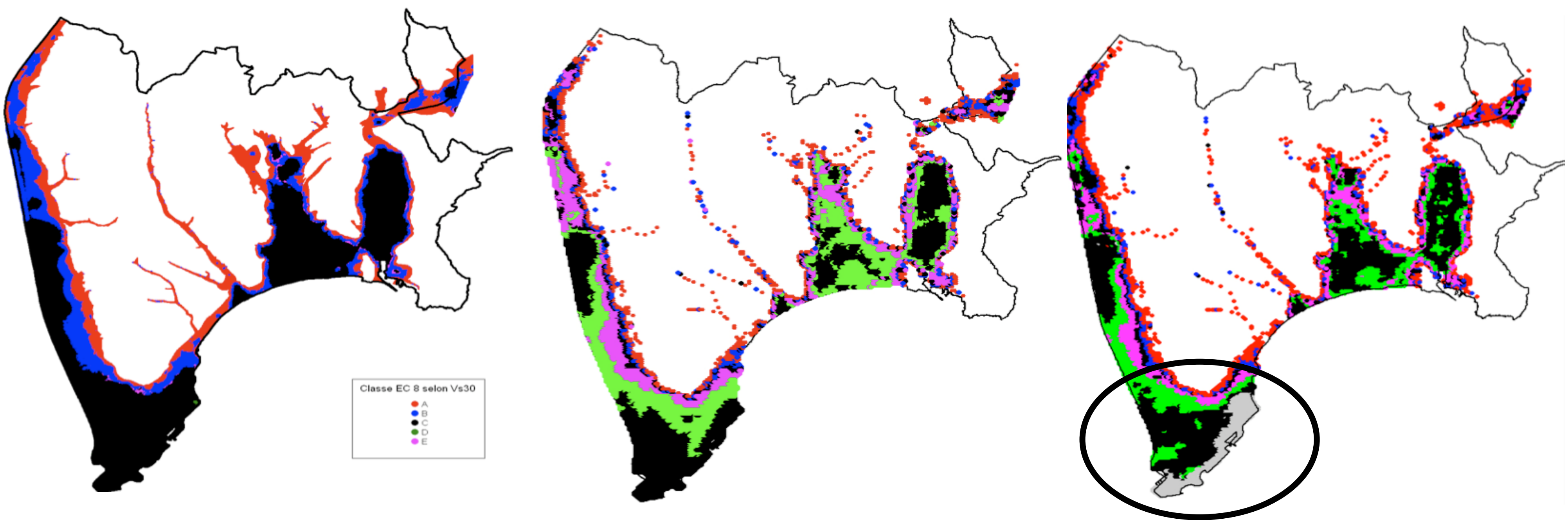


- ? Which to choose ?



Application to risk assessment : Consistency between hazard and vulnerability estimates

Rather detailed local hazard estimates

- frequency dependent amplification

Rudimentary vulnerability curves

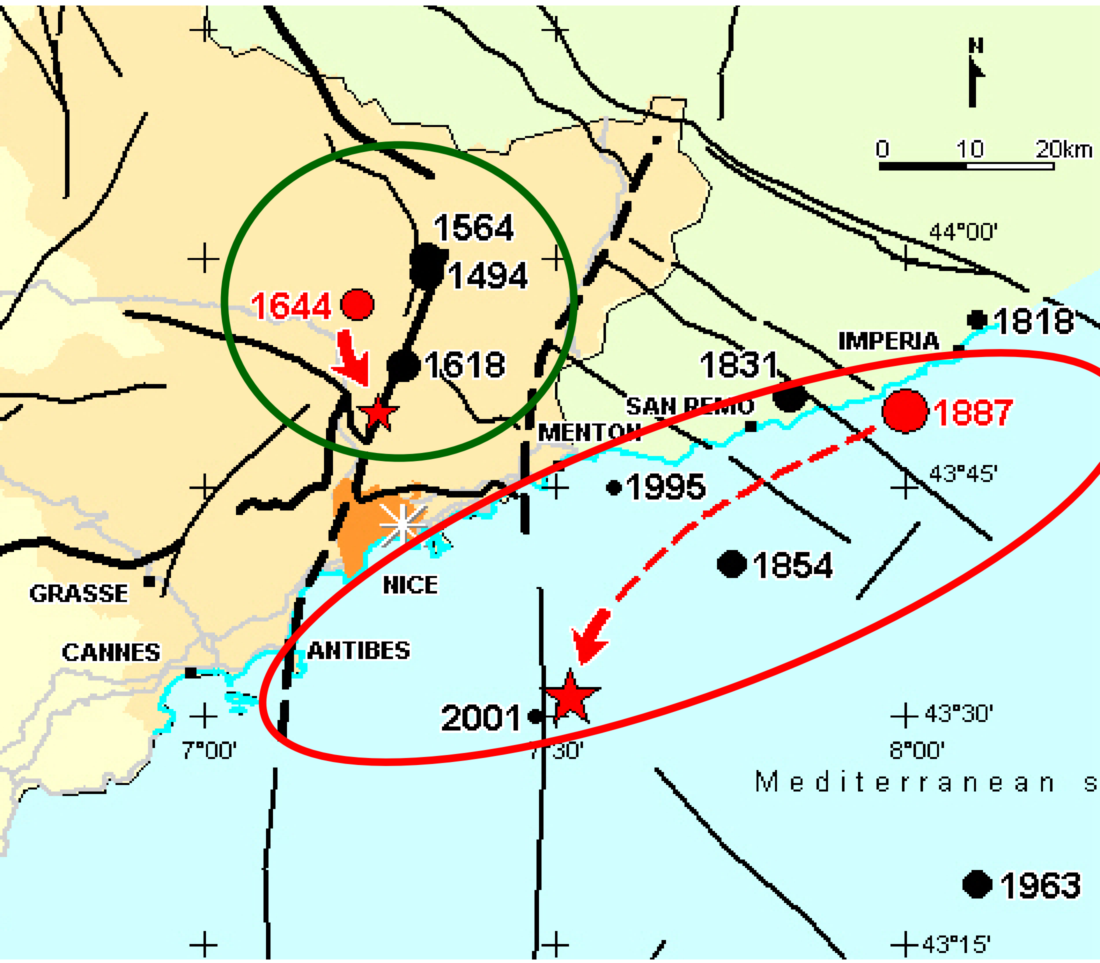
- Vulnerability Index → damage vs pga or Intensity

How to combine them for damage / risk assessment ?

- Scenario earthquakes for Nice
- Intensity value for reference rock
  - Mean VI / "homogeneous area" → mean damage
- ? how to modulate the intensity with site conditions ?
  - Assumption : $\Delta I_{max} = 2$
    - (reduction on hard rock : $\Delta I_{max}/3$, increase on soft soil : $2\ \Delta I_{max}/3$)
  - Accounting for the information on site and building frequencies
    - f(building) < f(site) : no effect
    - f(building) ≈ f(site) : maximim effect (ΔI_{max})
    - f(building) > f(site) : intermediate effect ($\Delta I_{max}/2$)
- Eestimation of the damage rate / "homogeneous area"

Scenario earthquakes

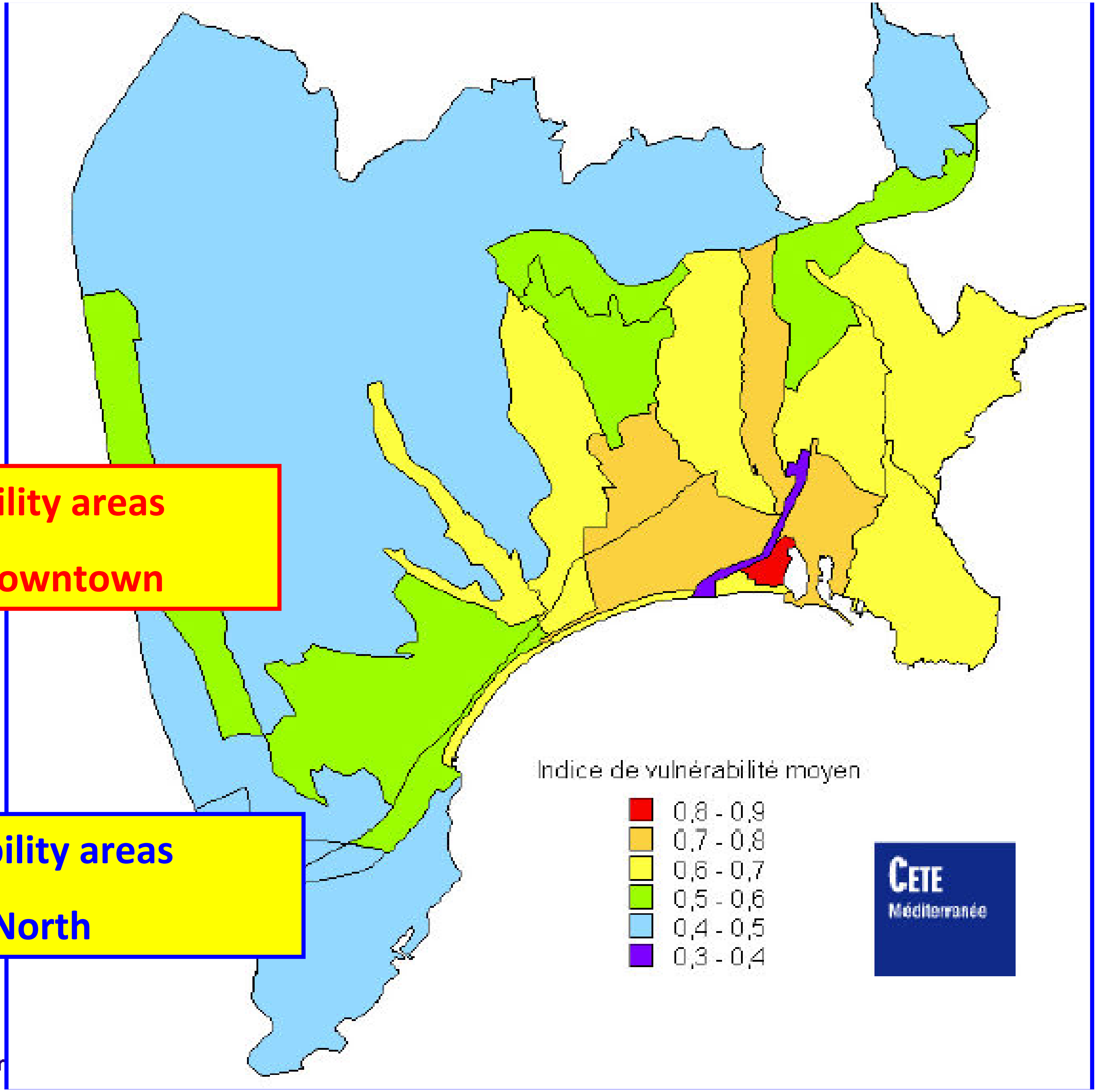
Inland



Date	Imax	I(Nice)	M
1564	VIII	V	? 5.7 ?
1464	VIII	VI	? 5.7 ?
1618	VIII	?	? 5.7 ?
1644	VIII	?	? 5.7 ?
Scénario 1: "Bouvon"	VIII	VI-VII	5.7
Date	Imax	I (Nice)	M
1831	VIII	?	5.7
1854	VII-VIII	VI	5.5
1887	IX	V	6.3
1963	VII-VIII	V	6.0
1989	VI	IV	4.5
1990	VI	III-IV	4.3
1995	VI	V	4.7
2001	VI	IV	4.8
Scénario 2 "Ligure"	IX	VII	6.3

Offshore

Mapping the "average" vulnerability index VI for areas with homogeneous building typology



Higher vulnerability areas

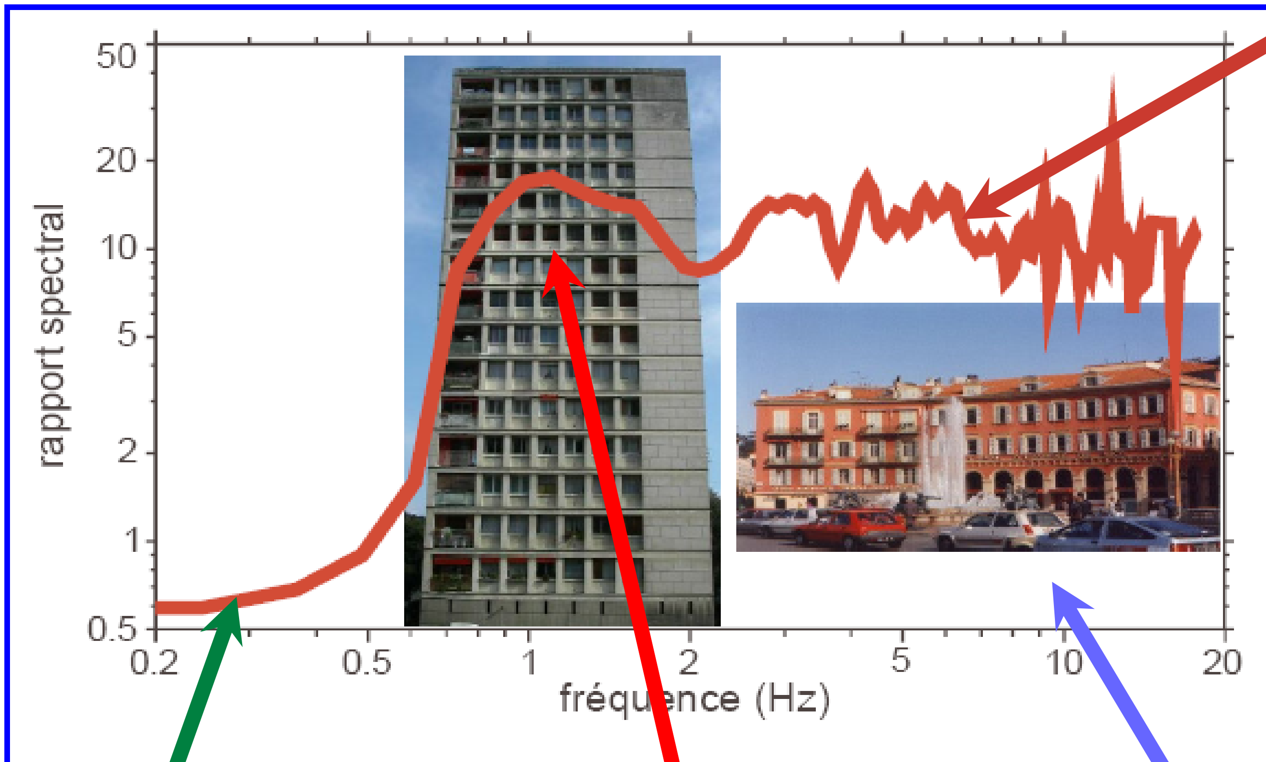
Historical city, downtown

Lower vulnerability areas

West and North

Relative location of building and soil frequencies

Site amplification



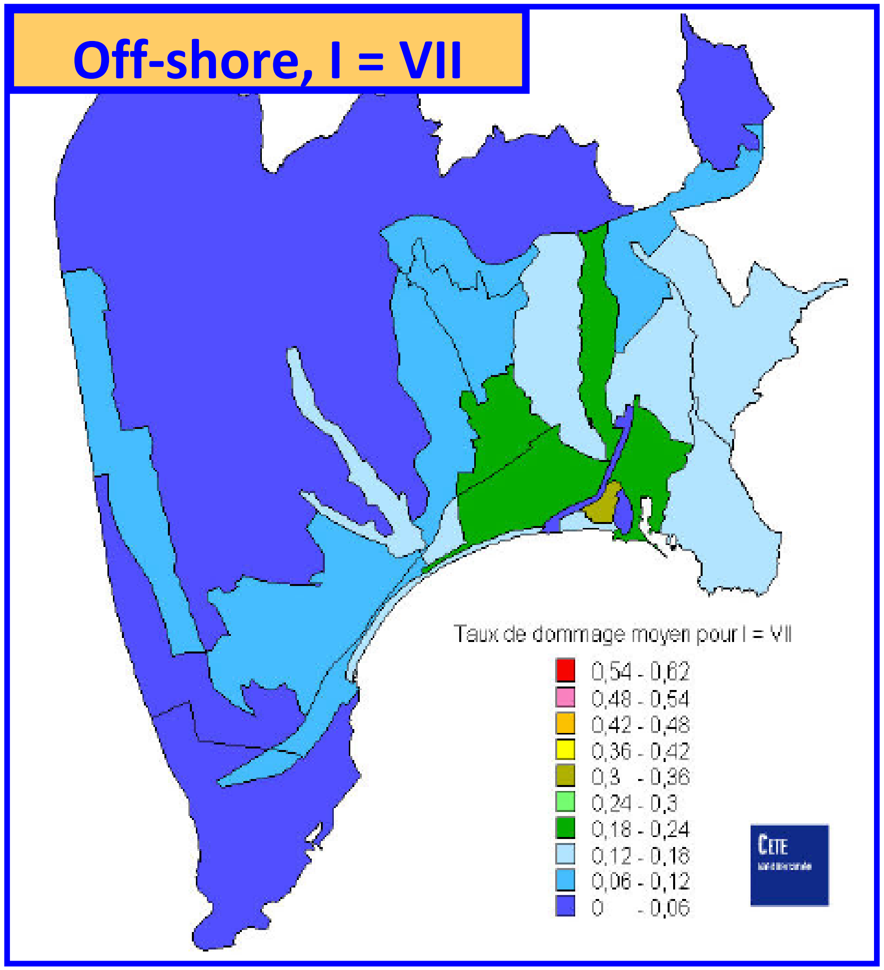
High rise / low frequency building : no amplification

Frequency coïncidence: maximum amplification

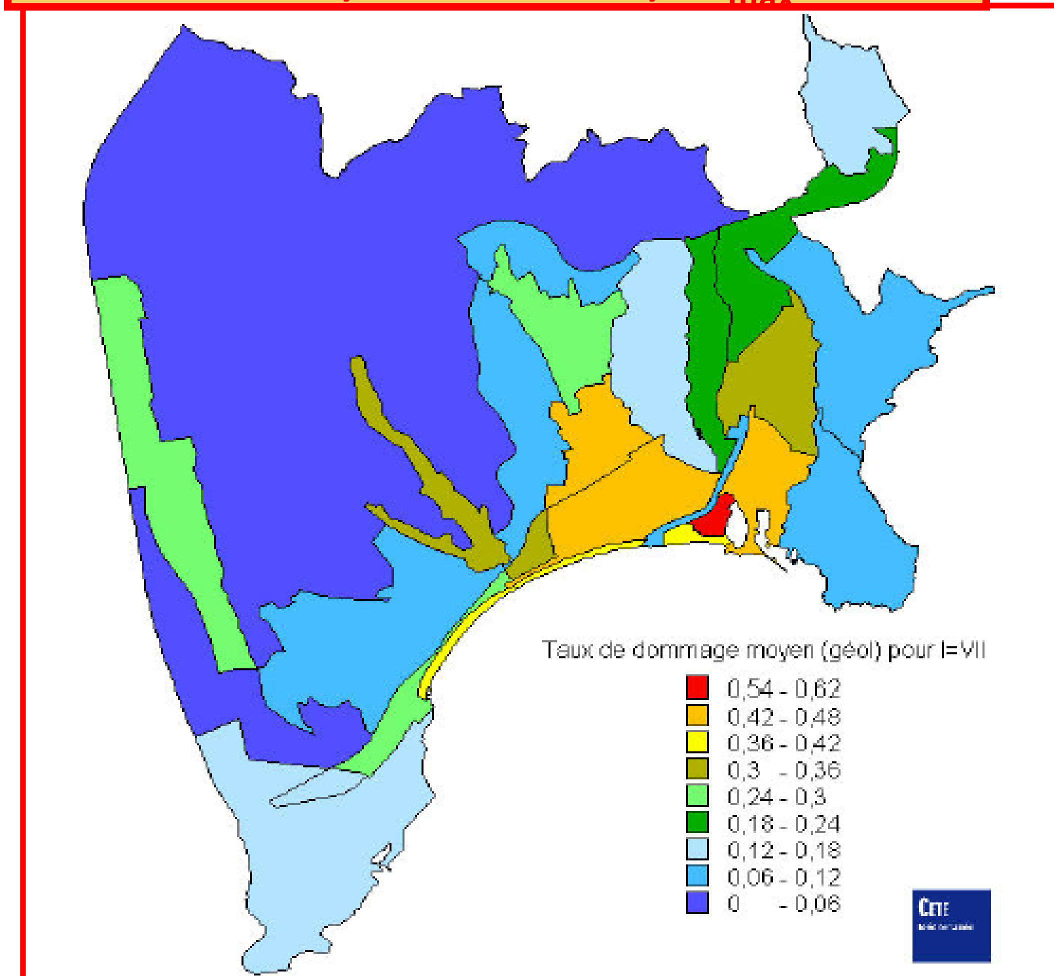
Low rise / high frequency building : intermediate amplification

Estimated damage rates

Off-shore, I = VII

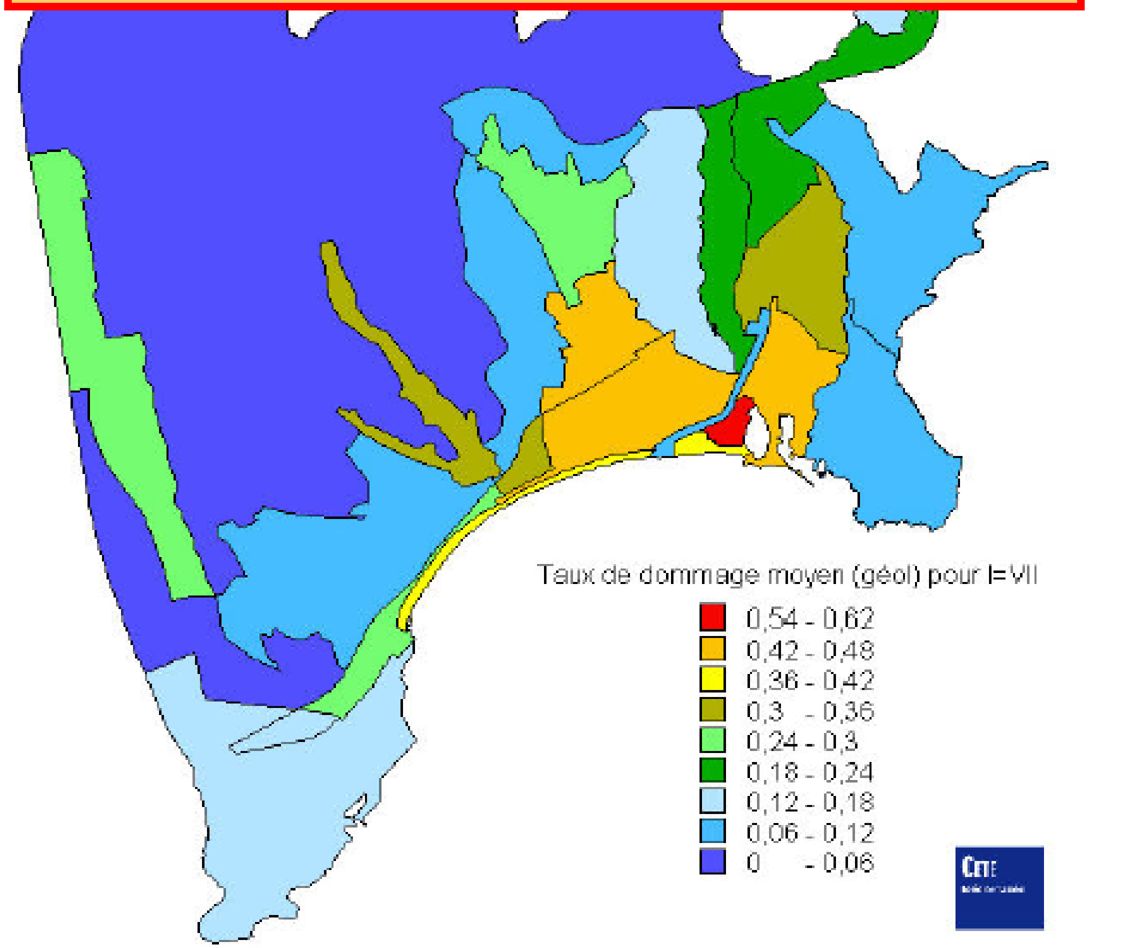


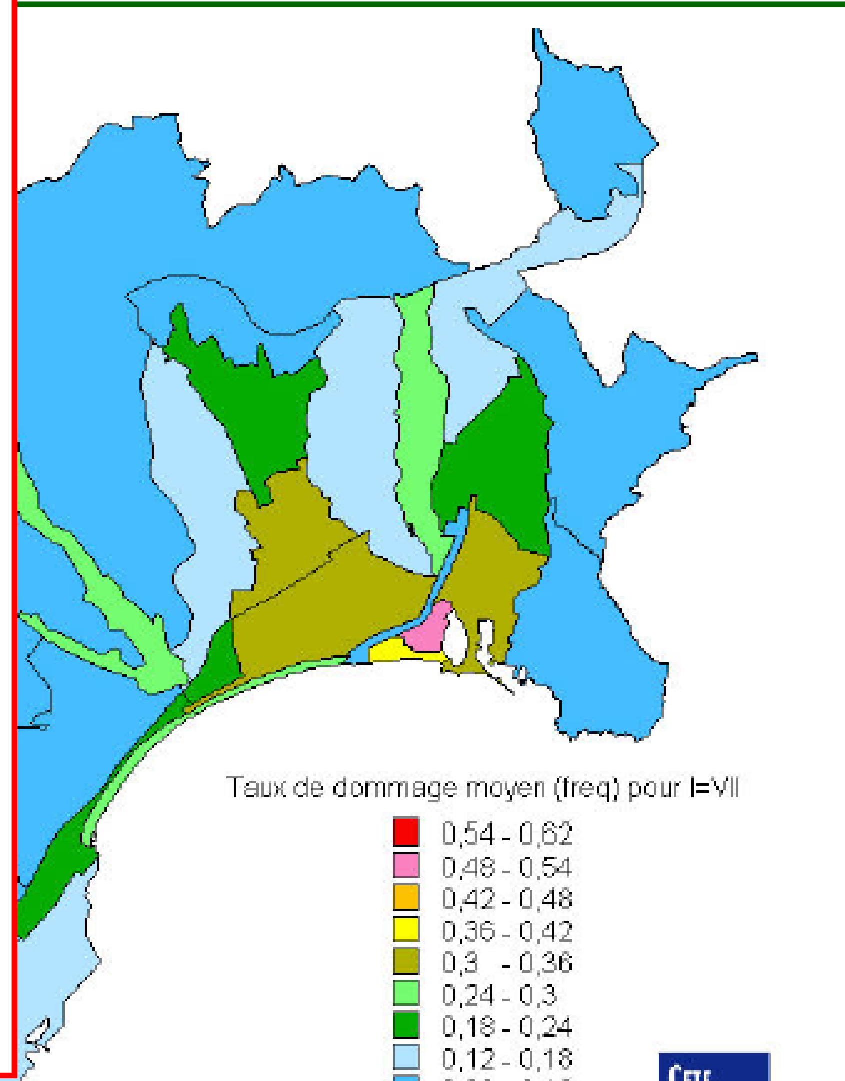
Off-shore, I = VII + site, ΔI_{max} = 2



Estimated damage rates

Off-shore, I = VII + site, ΔI_{max} = 2, without accounting for frequency information





Off-shore, I = VII + site, ΔI_{max} = 2, with accounting for frequency information

Maximum Intensity increment	Mean damage rate over the whole city		Variability within the city	
ΔI_{max}	No account for site/building frequencies	Accounting for the frequency information	No account for site/building frequencies	Accounting for the frequency information
$\Delta I_{max} = 0$	13%		3 à 33 %	
$\Delta I_{max} = 1$	15%	15%	5 to 47 %	5 to 42 %
$\Delta I_{max} = 2$	20%	17%	5 to 62 %	6 to 49 %
$\Delta I_{max} = 3$	25%	19%	5 to 74 %	7 to 57 %

Conclusions for these 3 examples

Mexico City

- One single parameter (f0) controls everything
- Locally built correlations after extensive investigations (all kinds)
- (Very) Soft soils : f_0 from microtremor (predominant or H/V)

Tehran

- Shallow information not enough for stiff sites over hard bedrock
- H/V technique does not provide good results
- Absolute need to calibrate with earthquake recordings at various sites
- Physics not well captured : difficult to interpolate / extrapolate

Nice

- Inconsistency between local hazard estimates from different technique
  - need to claibrate / validate with earthquake recordings !
- Preferred = empirical based on H/V + SAPE (f_0, V_{SZ})
- Consistency between hazard estimates and vulnerability estimates : to be improved
  - (update of vulnerability estimates to include frequency information)

Final comments

? "to hear your views on whether earthquake scenarios fine-tuned to microzone studies or global field assumptions would serve the purposes better"

Answer

- design purposes : reluctant to consider specific earthquake scenarios
- global field assumptions (= empirical correlations)
  - MUST be validated / tuned for the site / city under study (Ex.: Tehran)
  - May perform very well is some cases, very bad in some other
- fine-tuned microzonation studies :
  - SHOULD also be checked against instrumental recordings of earthquakes at least at a few sites
    - Caution for thick, stiff sedimentary sites (possible failure of H/V technique)
- No ideal solution adapted to all cases

HOWEVER…

Common point

- It is mandatory to have on site recordings of earthquakes at a few sites
  - Magnitude order (frequency band, amplification level)
  - Guidance / Constraint for physical interpretation AND extrapolation over the whole territory
- Better to understand the basic physics of the observations

My dream for the next decade

- Short term : an international pool of 200 portable instruments, dedicated to investigations on local seismic hazard in the EuroMed area
- Longer term : Massive deployment of cheap instruments

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Thank you / Merci