The Abdus Salam
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United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

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"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

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Site Effects and uncertainties

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Site effects and uncertainties

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Overview

Introduction on site effects

- ground shaking / induced
- Examples and order of magnitude

Physical Phenomena

- Surface topography
- Alluvial / sedimentary cover

Estimation methods

- Non-site specific techniques
  - GMPE
- Site specific methods
  - Numerical approach
  - Instrumental approach

Concluding comments

- recommendations

Site effects

Direct - ground shaking - site effects

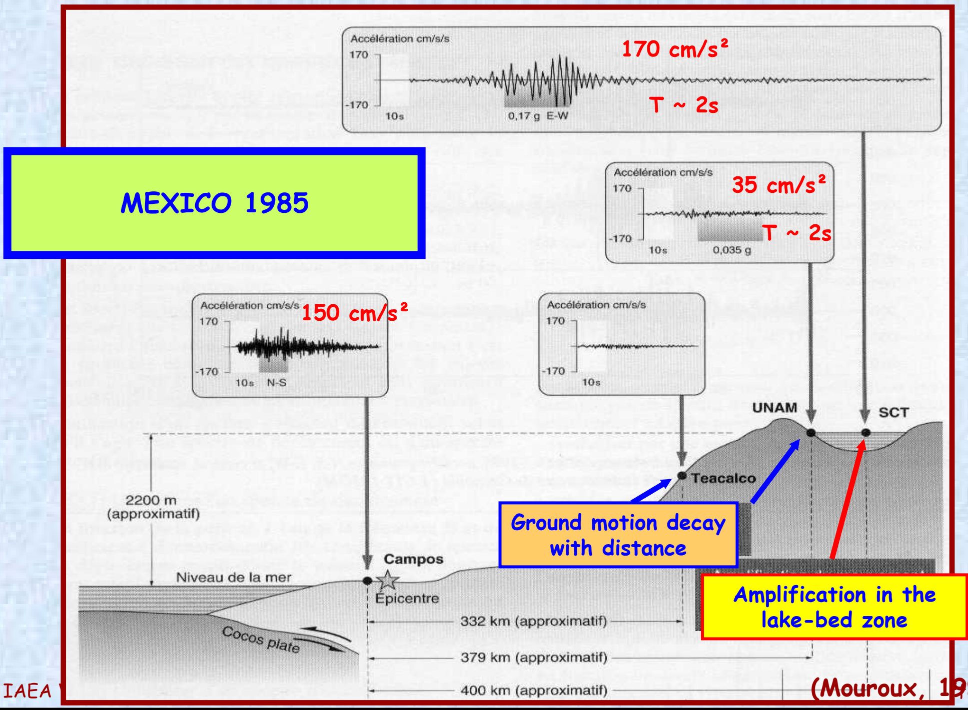
- Wave propagation effects, resulting in localized localized amplifications, (or deamplifications), highly variable with frequency, reaching up very high levels (> 10)
  - Surface topography
  - "Soft" surface deposits

Induced site effects

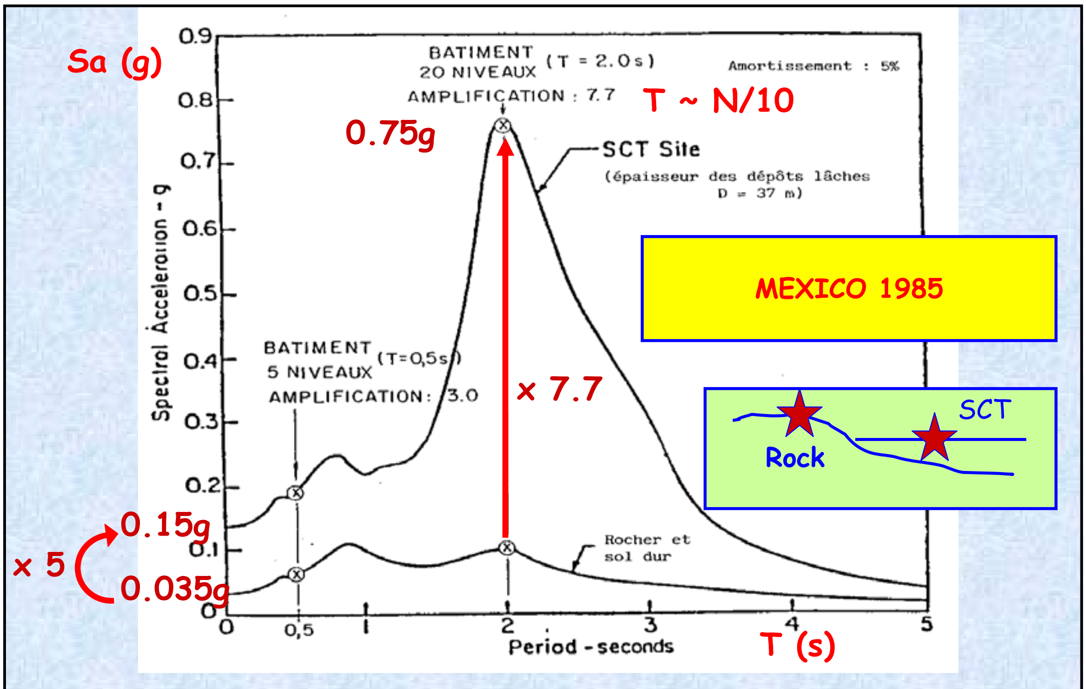
- Soil damage resulting in localized soil failures
  - Liquefaction of water saturated sandy deposits, settlements
  - Slope instabilities (slides, falls, debris flows, …)

Surface ruptures (fault trace)

Tsunamis local effects (bathymetry / topography)

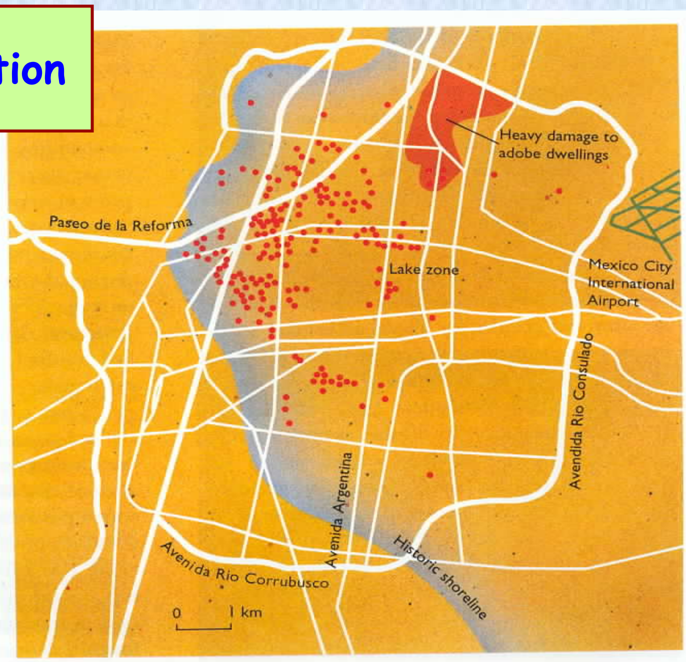


(Mouroux, 1999)



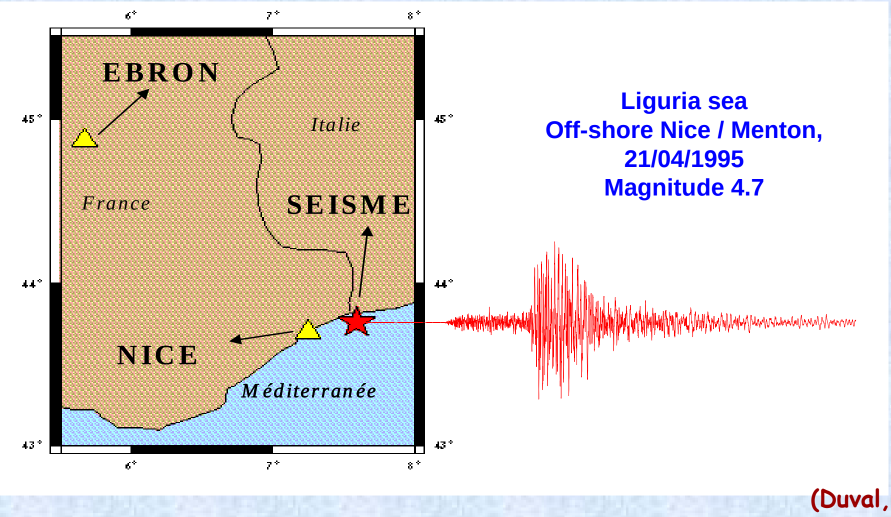
(Mouroux, 1999)

Damage distribution



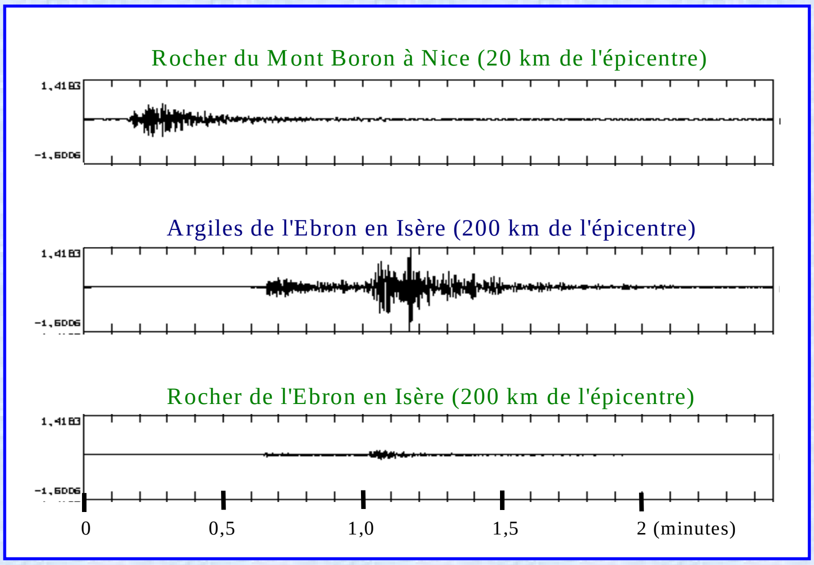
Heavily damaged and collapsed major structures were concentrated in the old lake zone of Mexico City. Each dot represents a heavily damaged or collapsed building.

Another example : bridge project over river Ebron (post glacial lacustrine clays)



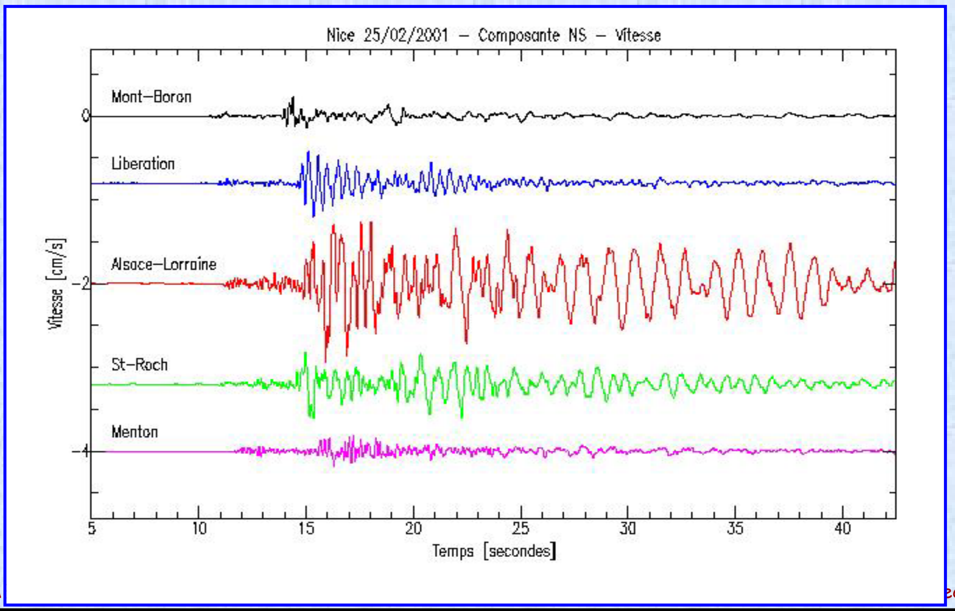
(Duval, 2002)

Recordings Nice + Ebron



(Duval, 2002)

Another example: downtown Nice



Ground shaking site effects

Repeated examples during (almost) all recent earthquakes

- Caracas 1967, Lima 1974, Mexico 1985, San Francisco 1989, Northridge 1994, Kobe 1995, Armenia 1999, Izmit 1999, Athens 1999, Gujarat 2001, Bam 2003,…

Amplification factors

- Intensity increment : ΔI = 1 to 2 very common
- Spectral domain (Fourier) : 5 common, 10 not exceptional
  (10 : corresponds to ΔM = 2)
- Relatively stable ($10^{\sigma}=2$)

Control, at least partially, sometimes totally, the damage distribution

Easier (less uneasy) to predict than source effects

⇒ Very interesting for mitigation

? Separation source / site ?

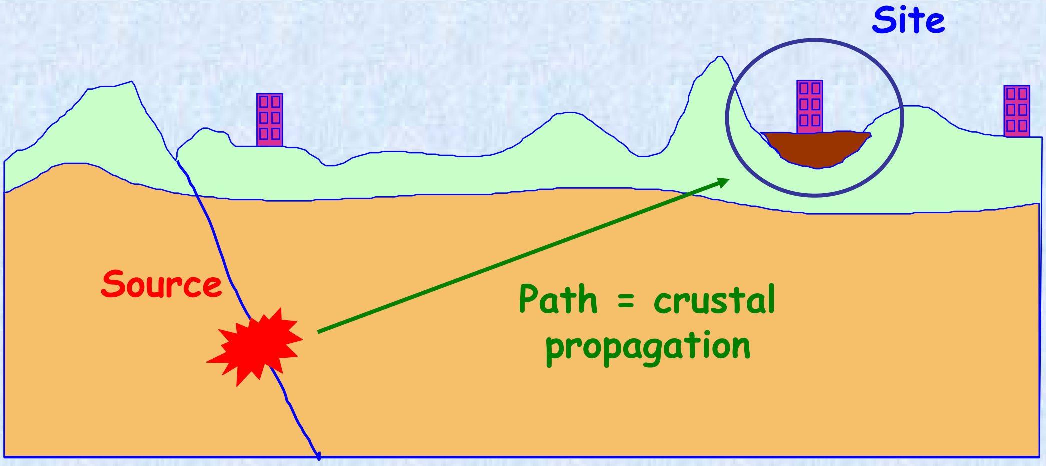
Ideally, a site response study should include

- rupture mechanism (source)
- wave propagation in the crust to bedrock top (path)
- how surface motion is influenced by soil layers located above the bedrock top
- possible coupling
  (wavefield, azimuth/incidence, shock waves, …)

In practice

- rupture mechanism too complex
- crustal velocity / damping characteristics poorly known
  ⇒ all variability included in PSHA
- site response analysis = response of the surface soil layers under "forced" top bedrock motion
  ⇒decoupling site response from wave emission and crustal propagation ???
  ⇒ only few theoretical studies to support or contradict this "forced" assumption

Source + Path + Site



Outline

Introduction on site effects

- ground shaking / induced
- Examples and order of magnitude

Physical Phenomena

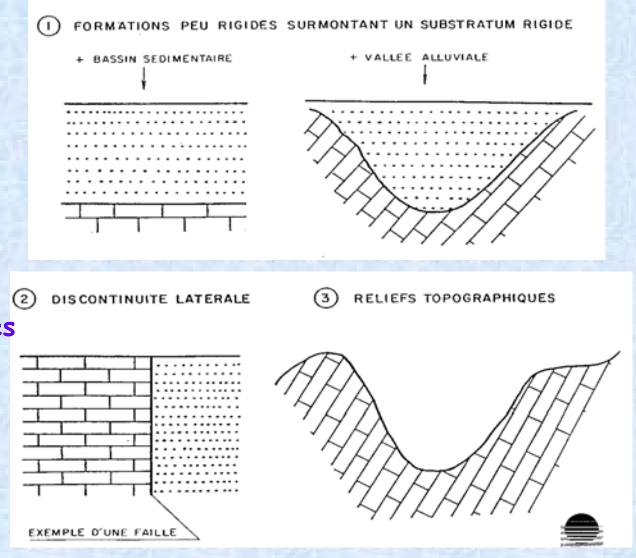
- Surface topography
- Alluvial / sedimentary cover

Sites prone to amplification

Soft layers

1D

2D, 3D



Lateral discontinuities

Surface topography

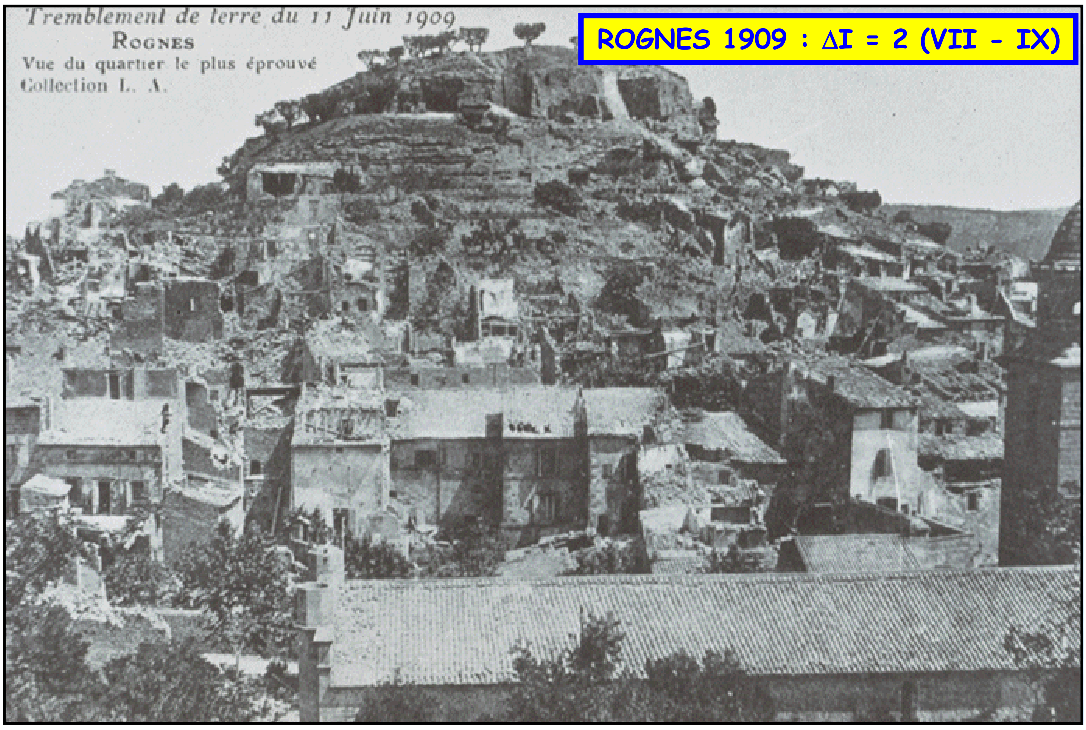
Underlying physics

Surface topography:

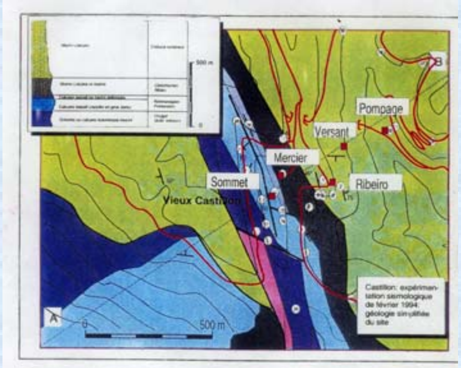
- Focusing on summit (convex) areas + diffraction
- Amplification, mainly on horizontal components
- Issue : Observed amplifications often (much) larger than computed values

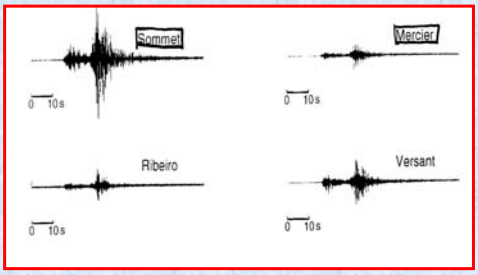
Soft cover

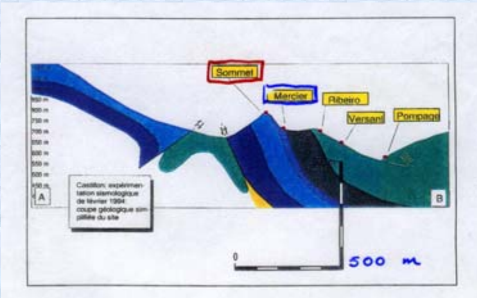
- Wave trapping and resonance
- 1D – 2D – 3D
- Non-linear behavior

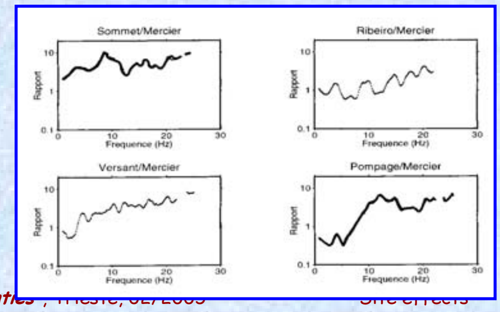


Example: Castillon

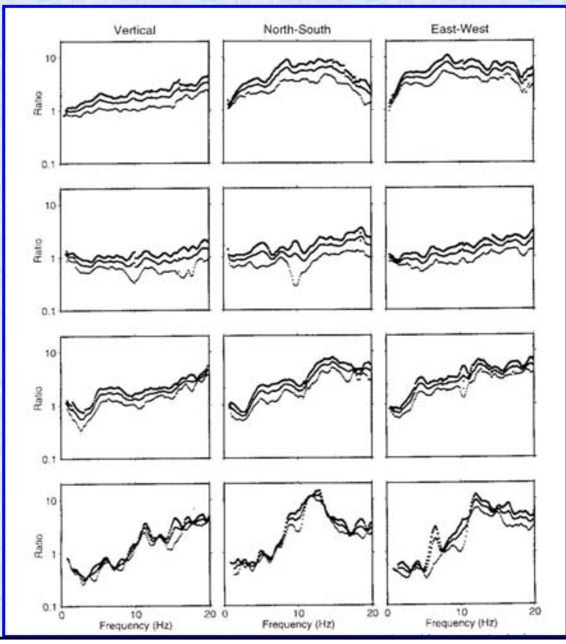


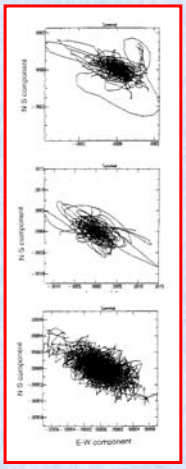


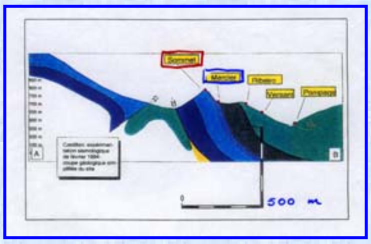




Example: Castillon



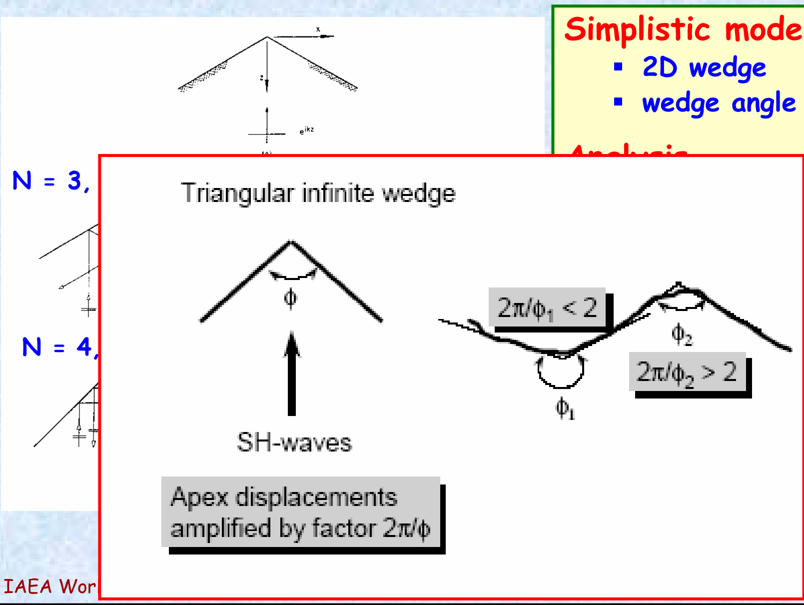




Focusing phenomena

N = 3,

N = 4,



Simplistic model

- 2D wedge
- wedge angle θ = 360°/n

n side slopes

s

in travel path ⇒

ys

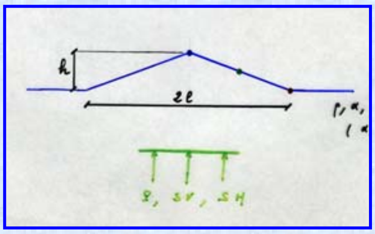
ve near the wedge

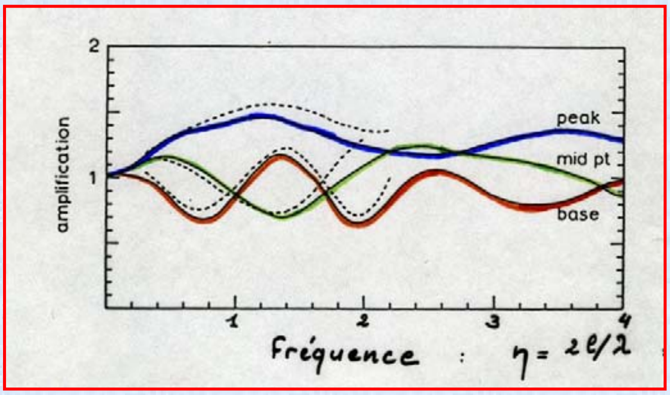
A = n

r θ = 120°

r θ = 90°

Modelling : example on a simple cross-section

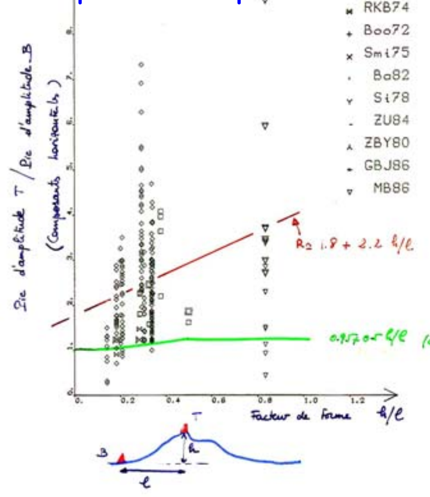




Surface topography effects : summary of results

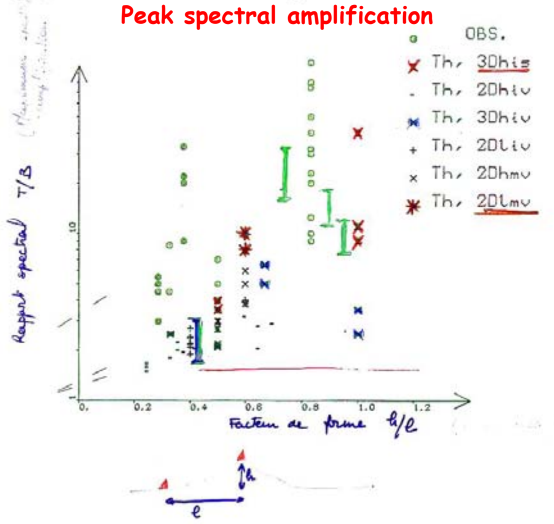
Time domain:

Amplification of peak values



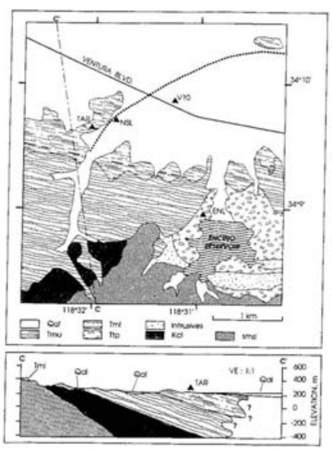
Frequency domain :

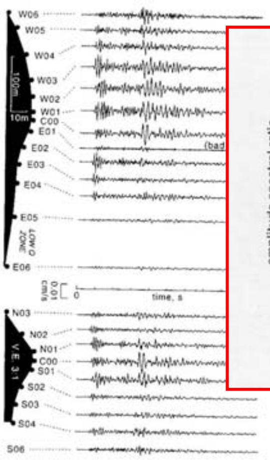
Peak spectral amplification

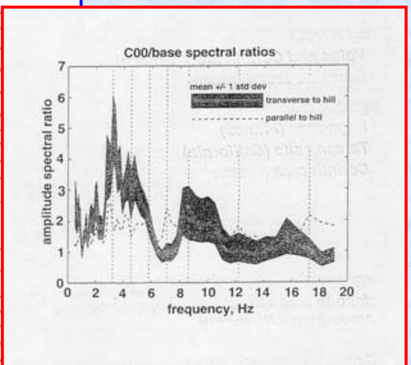


A peculiar example : Tarzana

(Northridge 1994: 1.8 g)







????

Surface topography effects: knowledge status

Main characteristics

- Top amplification (convex part) + foothill deamplification (concave)
  (for identical soil conditions)
- Frequency dependence
  Maximum effects for $\lambda = c/f \approx$ mountain width
- Lagest effects on Horizontal components
  - T > L >> V
- Possible range
  - 2 à > 10

Origin : not completely captured yet !

- Focusing / defocusing
- Reflexion coefficients on side slopes (oblique incidence)
- ??? Fracturation / decompression in summit areas

Accounting for them

- Codes : nothing in general; a few exceptions however (PS92, EC8, Maximum amplification = 1.4, no frequency dependence)
- Specific studies: numerical approach possible, but instrumental approach MANDATORY

TOPOGRAPHY COEFFICIENT PS92

5.2.4 Coefficient d'amplification topographique

Il est tenu compte d'un coefficient multiplicateur τ dit d'amplification topographique, pour les ouvrages situés en rebord de crête.

Si l'on considère une arête C (voir figure 7) délimitant un versant aval de pente I (tangente de l'angle de pente) et un versant amont de pente i, et si :

- $H \geq 10$ m (H étant la hauteur de l'arête au-dessus de la base du relief)
- $i \leq I/3$

Le coefficient τ :

- prend la valeur :

$\tau = 1$ pour

$\tau = 1 + 0{,}8\,(I - i - 0{,}4)$ pour

$\tau = 1{,}40$ pour

I et i sont pris en valeur algébrique

Sur le tronçon CB du versant amont défini par la longueur b d

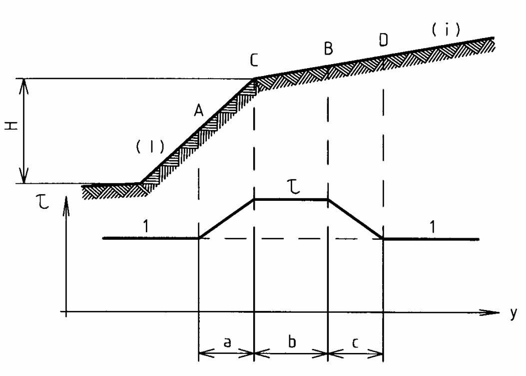
$$b = \text{minimum}\begin{cases} 20I \\ \dfrac{H+10}{4} \end{cases}$$

- fait l'objet d'un raccordement linéaire entre les valeurs

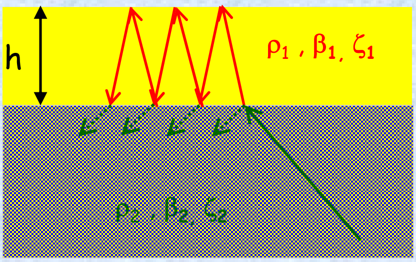
$a = AC = H/3$

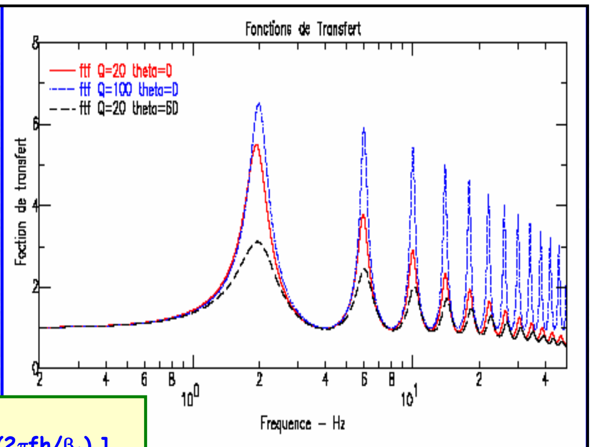
$c = BD = H/4$

- prend la valeur 1 à l'aval du point A et à l'amont du poi



Resonance 1 layer





Transfer function (Fourier)

$H(f) = 2\,C / [C\ .\ \cos(2\pi f h/\beta_1) + i.\ \sin(2\pi f h/\beta_1)\,]$

Resonance frequencies

- Fundamental mode: $f_0 = \beta_1/4h$
- Harmonics $f_n = (2n+1)\,f_0$

Amplification

- Elastif case
  $A_0 = |H(f_0)/2| = C = \rho_2.\beta_2/\rho_1.\beta_1$
- With damping ζ_1:
  $A_0 = C / (1 + 0{,}5\,\pi\,\zeta_1\,C)$

Typical values

Frequency $f_0 = \beta_1/4h$

- Depends only on surface layer characteristics

h \ β_1	50	100	200	400	800
5	2.5	5.0	10.0	20.	40.
10	1.25	2.5	5.	10.	20.
20	0.62	1.25	2.5	5.	10.
50	0.25	0.5	1.0	2.5	4.
100	-	0.25	0.5	1.0	2.
200	-	-	0.25	0.5	1.
500	-	-	-	0.25	0.4

! Weathered rock!

Amplification

- $A_0 = C / (1 + 0{,}5\,\pi\,\zeta_1\,C)$,
- $C = \rho_2.\beta_2/\rho_1.\beta_1$
- Also depends on bedrock !

Density conrast ρ_2/ρ_1

≤ 1.8

Velocity contrast β_2/β_1

β_2 up to 2.5 km/s

β_1 up to 50 m/s

usual values β_2/β_1 : 3-4

Extreme values β_2/β_1 : 10-15

Damping ζ_1

ζ_1 from 1% to 20%

No (anti-) correlation ζ_1/β_1

Resulting values for A_0

≤ 10

Weathered rock

It is customary to define "seismic bedrock" as

- lithological bedrock, or
- material with vs > 800 m/s

  (⇒ "reference site")

Weathering may produce surface Vs gradient

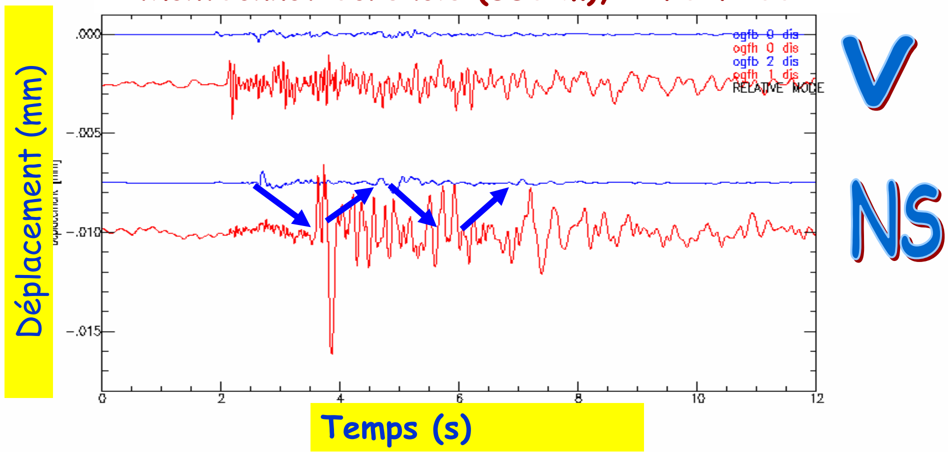
- can induce (HF) amplification at rock surface
- frequency content is modified
- results in errors if this motion is used as "reference motion"

  (GMPE !!!)

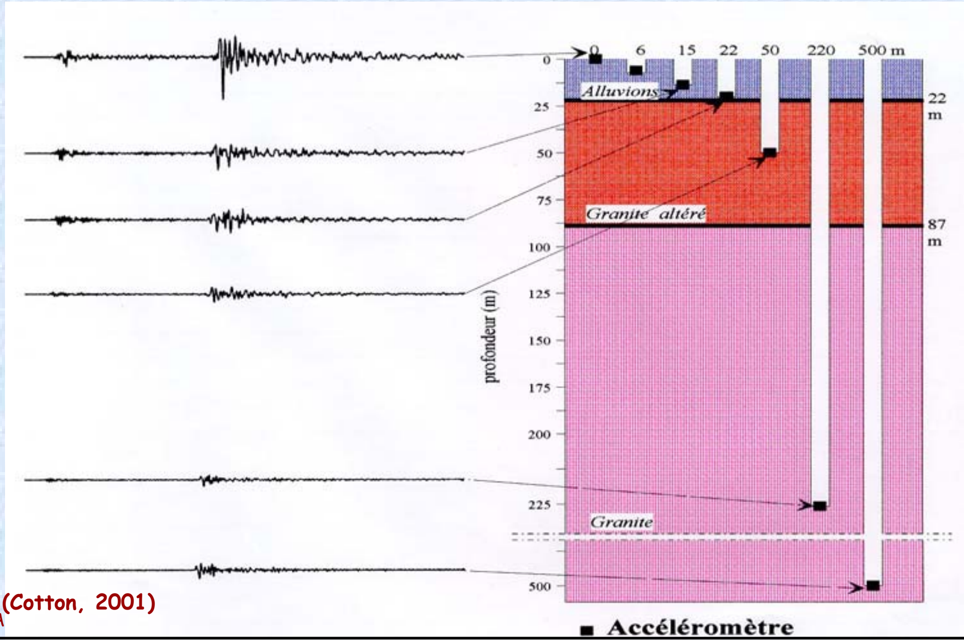
- (A related example : Argostoli station in Greece)

Example of vertical reverberations

Montbonnot borehole (550 m), 11/01/2001



Another example: Garner Valley (CA) downhole array



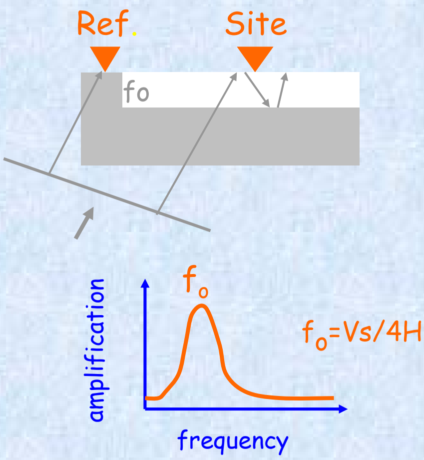
(Cotton, 2001)

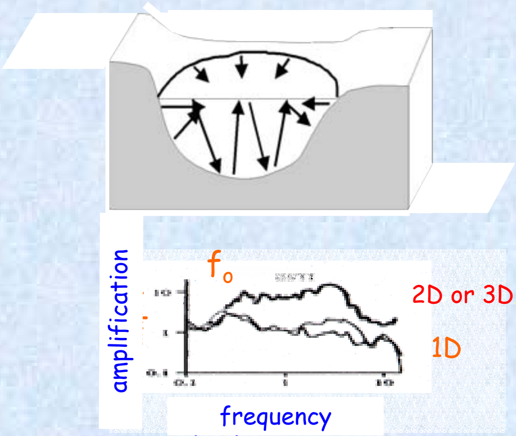
IAEA

Site effects with complex subsyrface topography

1) 1D case :
vertical reverberationsn

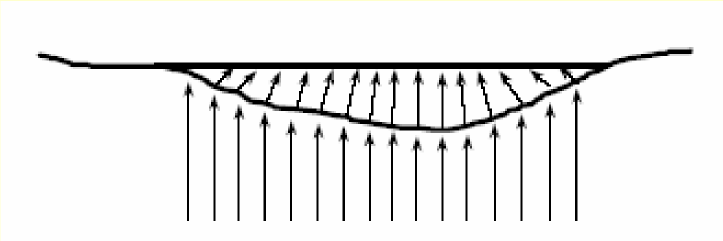
2) 2D / 3D case
lateral reverberations



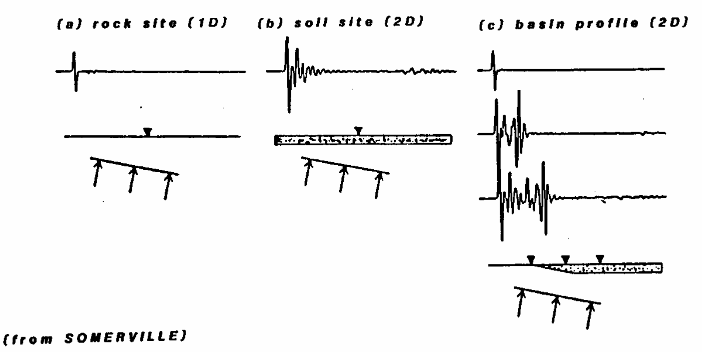


Basin effects

Alluvial basins common in many populated areas
Highly variable depths, widths, shapes
Generally filled with softer material
Can refract waves to "focus" energy
Can lead to the development of surface waves

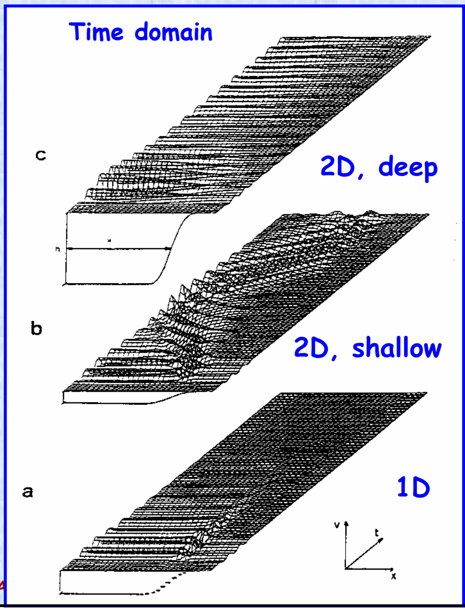


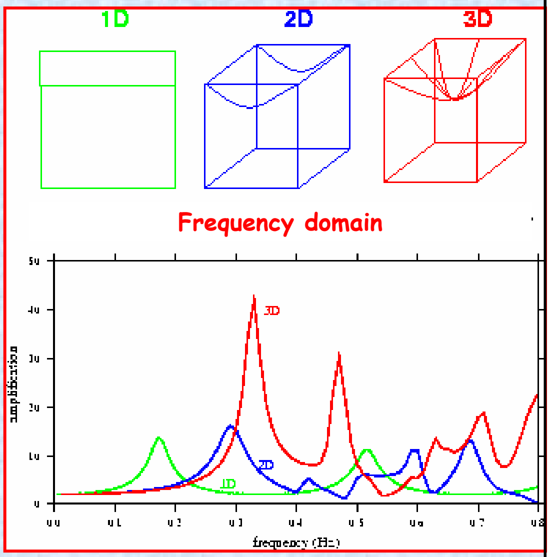
Site effects on valley edges



. Finite-difference SH velocity synthetics for (a) a rock site, (b) 1D soil site, and (c) a profile of stations across the basin margin. For stations located on the sediments, there is a large amplification relative to the rock site simulation. Furthermore, the basin profile shows the development of a large amplitude Love wave at the basin margin, which then propagates into the basin with a slow apparent velocity.

Site effects in valley centers





Lateral reverberations in a deep valley : Grenoble
An example of numerical simulation

Moczo, Kristek & Bettig (1999)

Horizontal Component NS

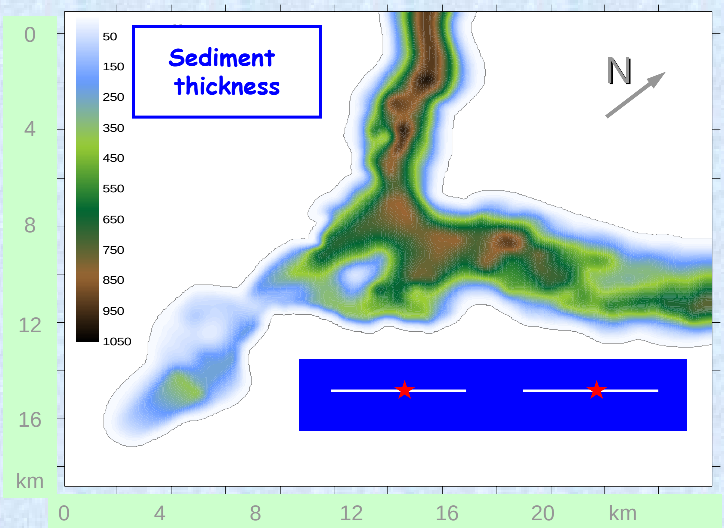
Measurements in Grenoble

(dense array= seismological antenna)

80% of the total signal energy is carried by locally generated surface waves (lateral reverberations)

New model for a priori calculations
(earthquakes M=5.5 on the Belledonne fault)

Kristek, Galis, Moczo, et al., 2004



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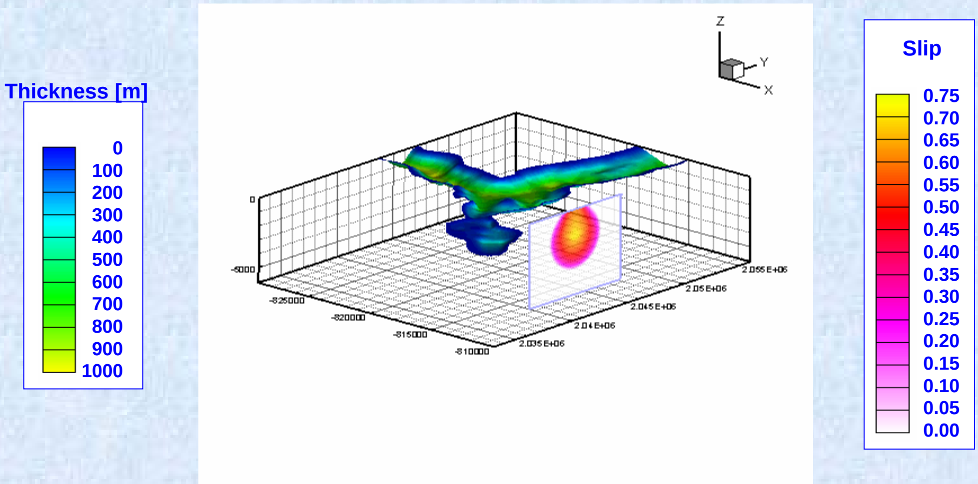
Grenoble model : 3D basin + hypothétical circular source



Kristek, Galis, Moczo, et al., 2004

IAEA Workshop "*Uncertainties in seismic hazard uncertainties*", Trieste, 02/2005 — Site effects

Ground motion modelling for local events (two positions)

Source to the SW

Source to the NE

Kristek, Galis, Moczo, et al., 2004

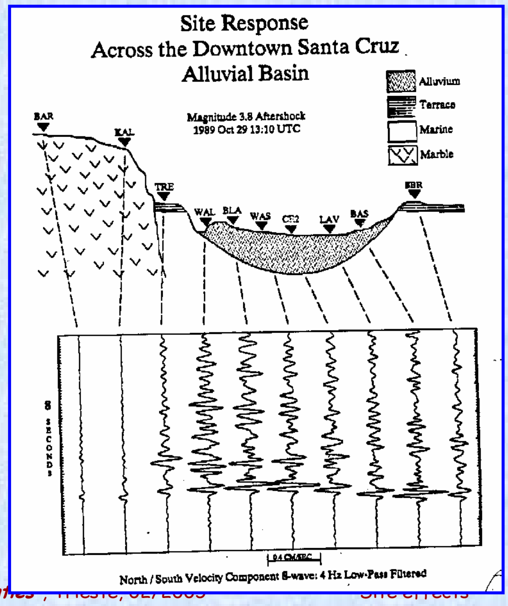
Site effects in valleys / basins

Wave diffraction

- Verticales and lateral reverberations
- Diffraction : from body waves to surface waves
- More efficient trapping

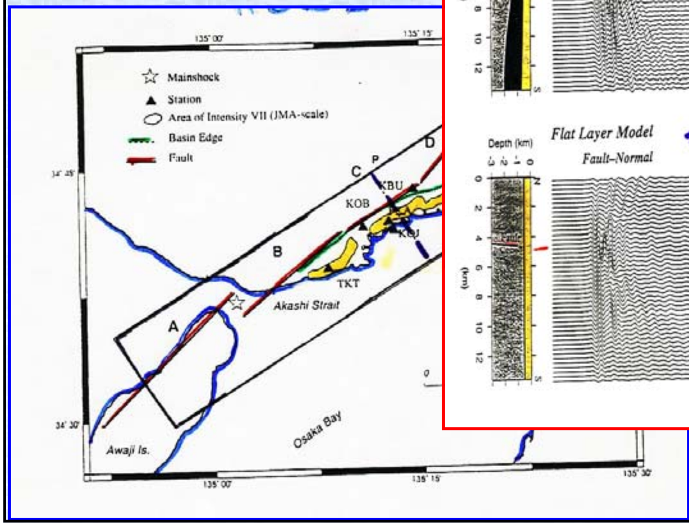
Consequences

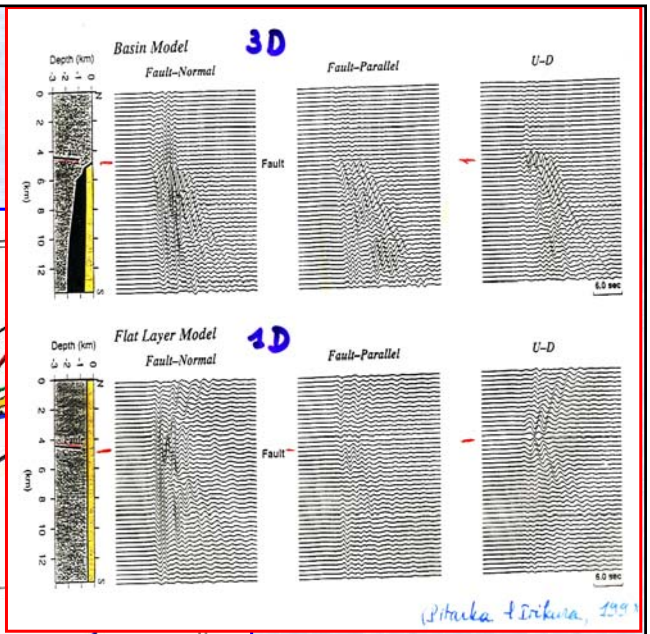
- Duration increase
- Amplification increase



IAEA Workshop "*Uncertainties in seismic hazard uncertain*

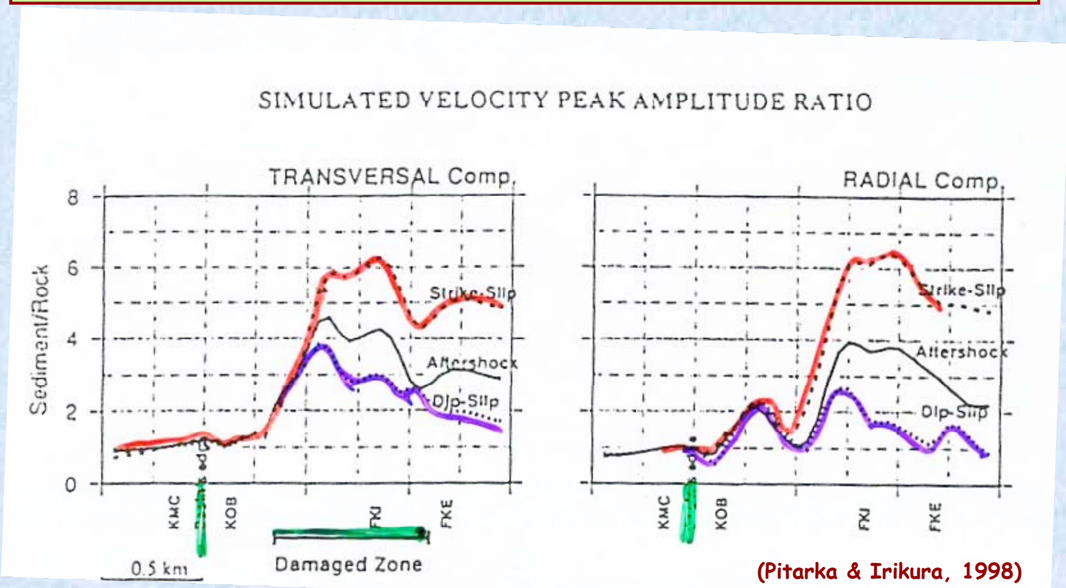
Example : Kobé





(Pitarka & Irikura, 1998)

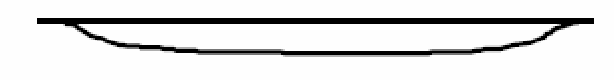
Kobe : damage distribution and basin edge effects



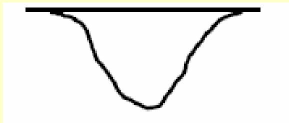
(Pitarka & Irikura, 1998)

Basin effects : depend on shape

Wide, shallow basin



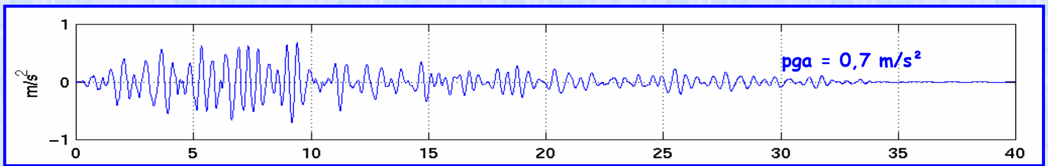
- 1D analysis may be OK in the center
  - (if damping large enough !)
- 2D effects may be important near the edges



Deep, narrow basin

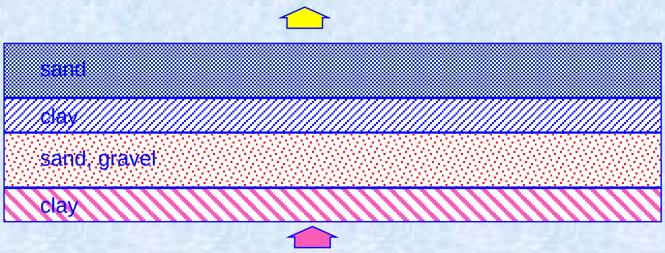
- 1D analysis may not be (is not) applicable

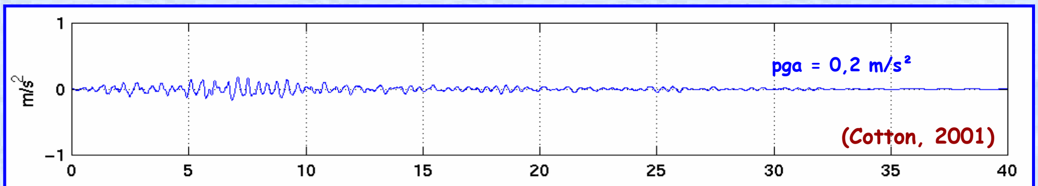
Soil non - linearities



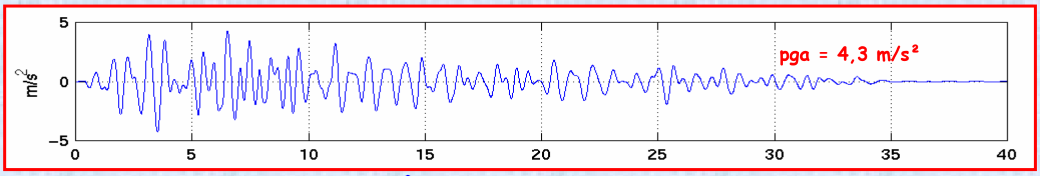
"weak" event:

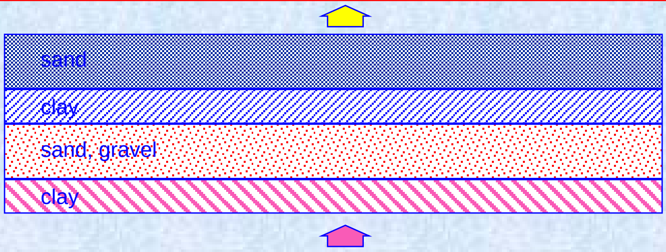
soil / rock = 3,5





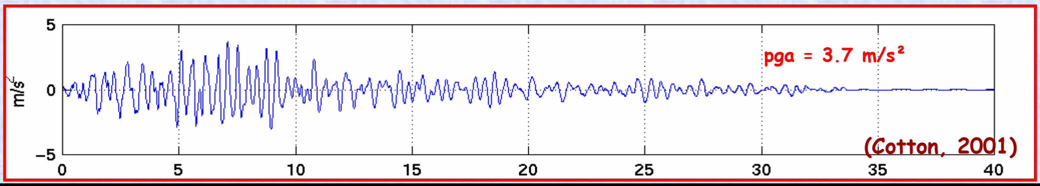
Soil non-linearities





"strong" event:

soil / rock = 1,2



(Cotton, 2001)

Non-linear behavior

Origin: Soil degradation under large deformation

- decrease of shear modulus
- Increase of damping

Consequences

Fundamental frequency f_0

$f_0 = \beta_1/4h,\ \beta_1 = (G_1/\rho_1)^{0.5}$

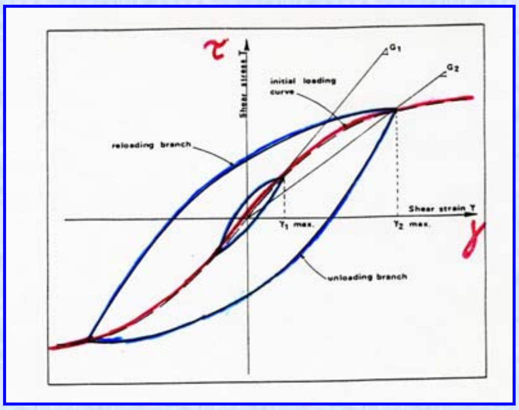
$\Rightarrow$ Decrease of f_0

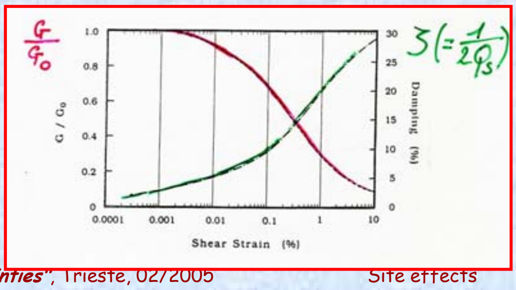
Amplification A_0

$A_0 = C / (1 + 0,5\ \pi\ \zeta_1\ C)$

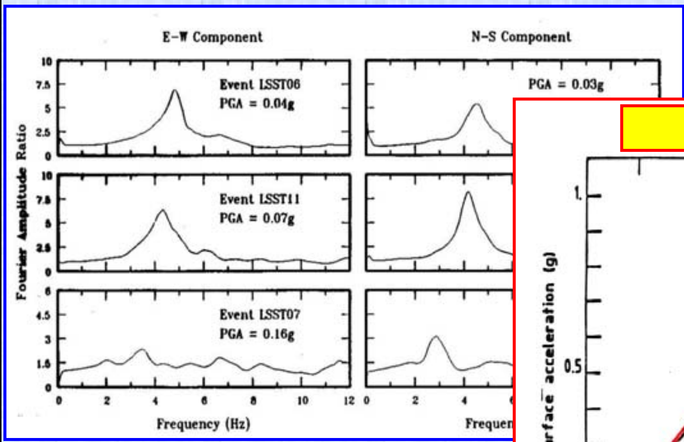
$C = \rho_2.\beta_2/\rho_1.\beta_1 \Uparrow\ ,\ \zeta_1 \Downarrow$

$\Rightarrow$ Decrease of A_0



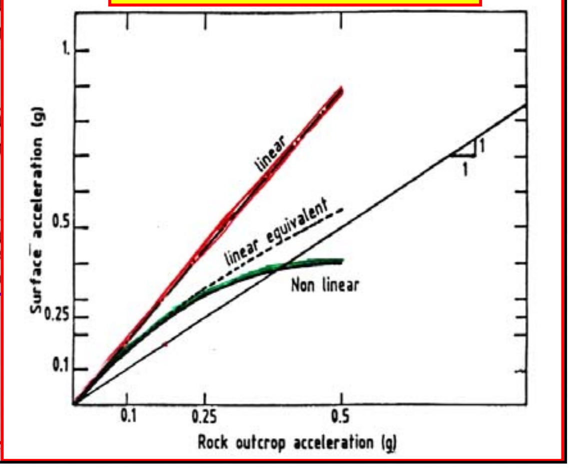


Consequences



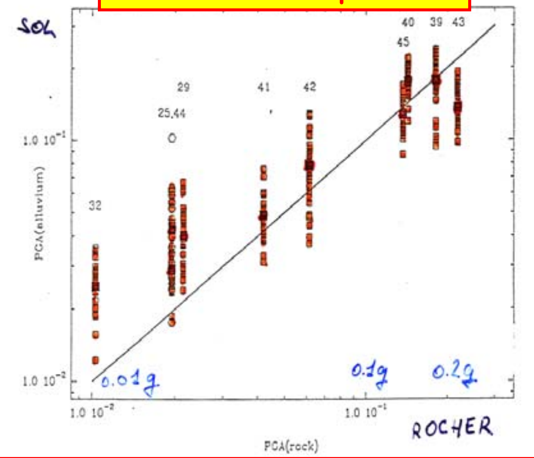
Transfer functions

Peak acceleration

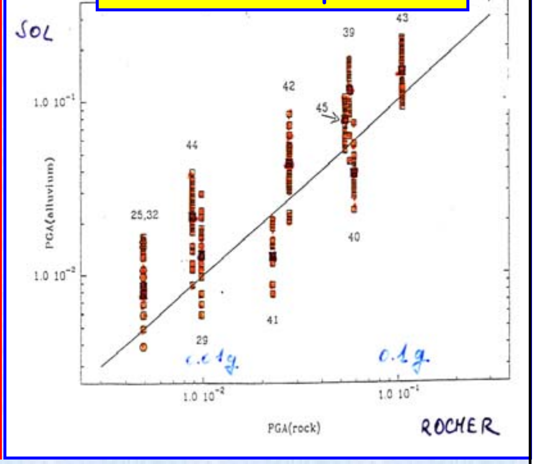


Pga Observations (Taiwan, SMART1)

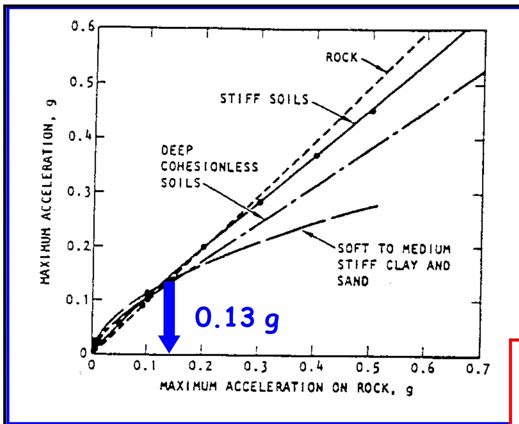
Horizontal component



Vertical component

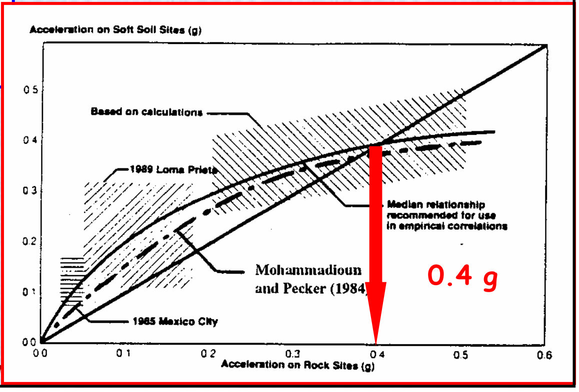


Engineering practice



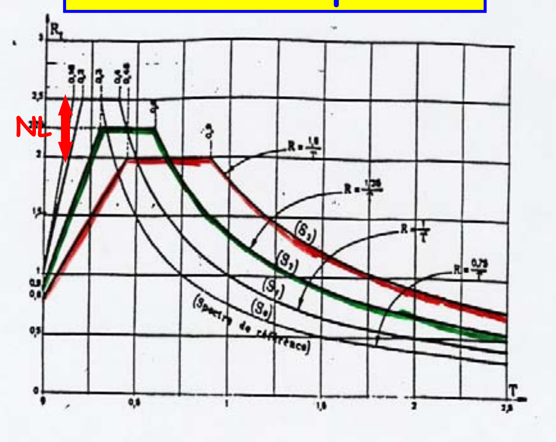
Before 1985

After 1990

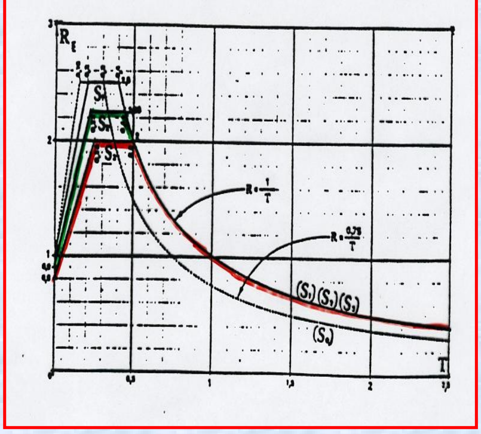


PS92 spectra

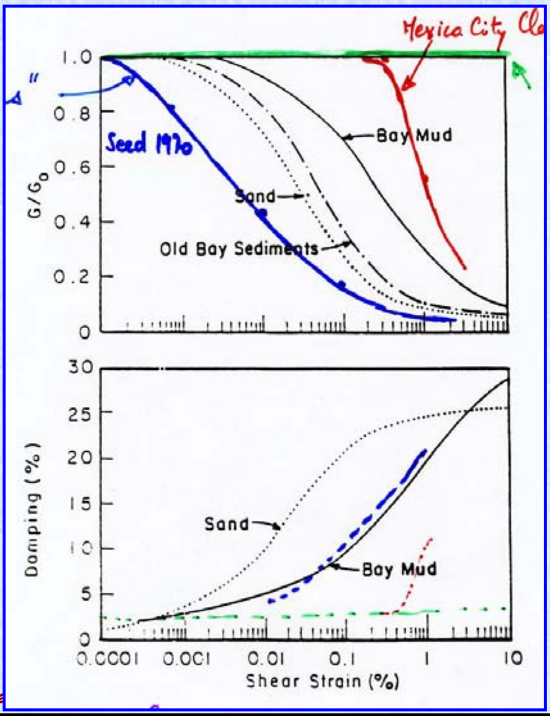
PS92 : Hz Spectra



PS92 : V Spectra



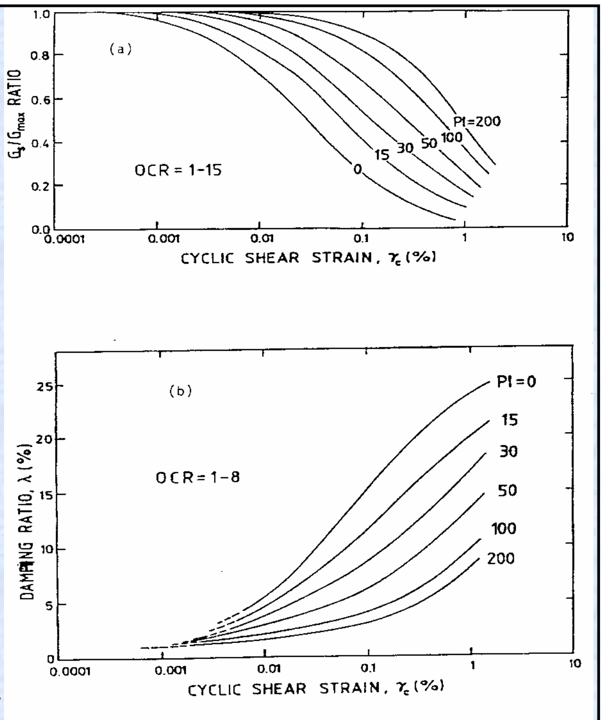
Non-linear degradation curves: evolution with time



Non-linear degradation curves

Vucetic & Dobry:

mainly controlled by plasticity index



Overview

Introduction on site effects
- ground shaking / induced
- Examples and order of magnitude

Physical Phenomena
- Surface topography
- Alluvial / sedimentary cover

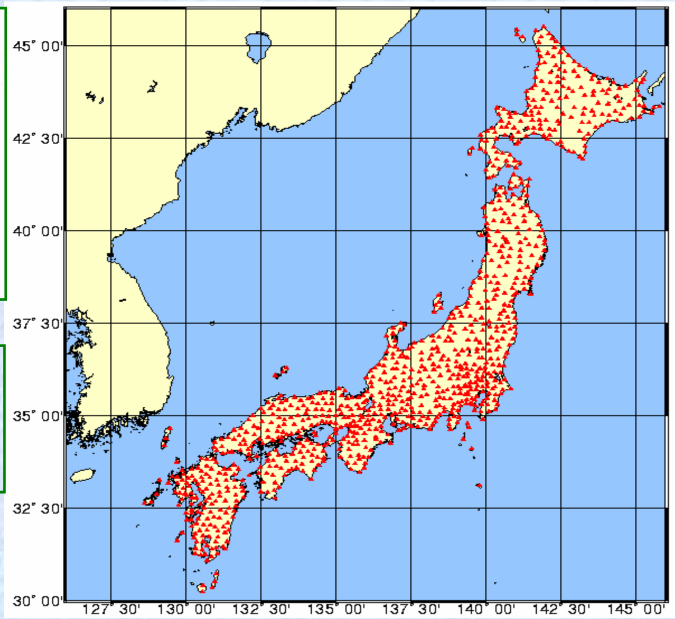
Estimation methods
- Non-site specific techniques
  - GMPE
- Site specific methods
  - Numerical approach
  - Instrumental approach

Estimation methods

1 - Non-site specific methods: Standard, simple approach
- Regulatory approach
  - Surface topography
  - Site classification and spectral shapes
    - Site soil profile (30 top meters only ?)
- Empirical relationships
  - Empirical "attenuation relationships"
  - Statistical correlations (? Quality and reliability of base data ?)

2 - Numerical approach

3 - Instrumental approach

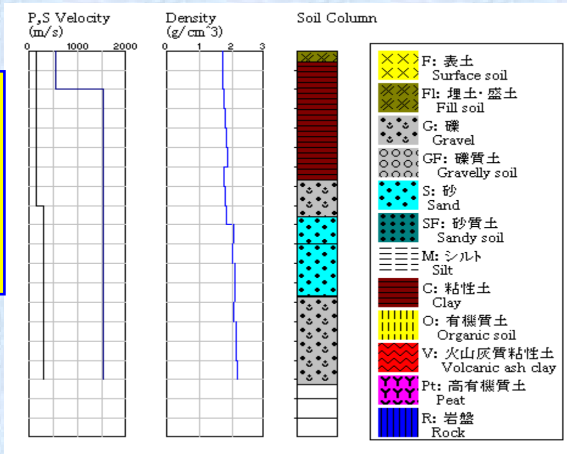


1000 accelerometres

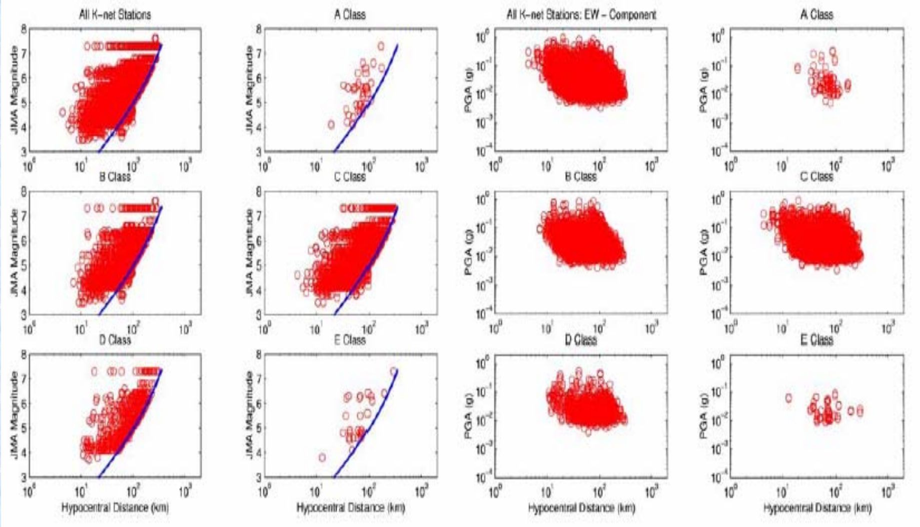
mesh = 25 km

K-NET : Geotechnical data for each station

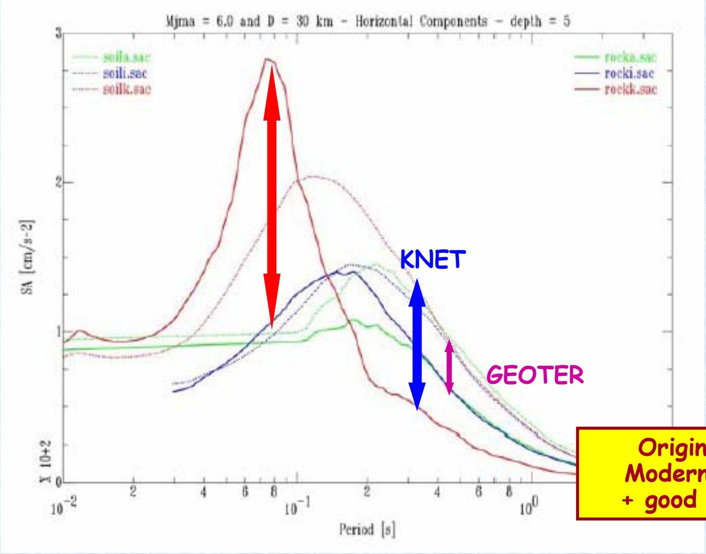
- penetrometer test
- P, S velocities
- density
- geological log



KNET 6 year data



Comparison with 2 other GMPE for M=6.0 - D=30 km



Larger short period content

Larger site-to-site differences at intermediate and long pariods

Origin: Japanese context ?
Modern, digital instruments ?
+ good site characterization ?

Estimation in site-specific studies

1 - non-site specific approach

2 - Numerical approach

- **Methods :**
  - OverSimplified : hand-calculations (1D, f_0)
  - 1D, 2D-3D,
  - Linear, Linear Equivalent, Non-linar
  - Plane waves (vertical incidence), oblique plane waves, with source (far / distant)
- **? Input parameters for modelling**
  - Specific site surveys
  - Correlations with other, simpler, "static", soil parameters

3 - Instrumental approach

Relevant parameters for wave propagation effects

Geometrical information

- 1D : thicknesses h_i for each geotechnical unit i
- 2D, 3D : geometry of each interface $z_i(x,y)$

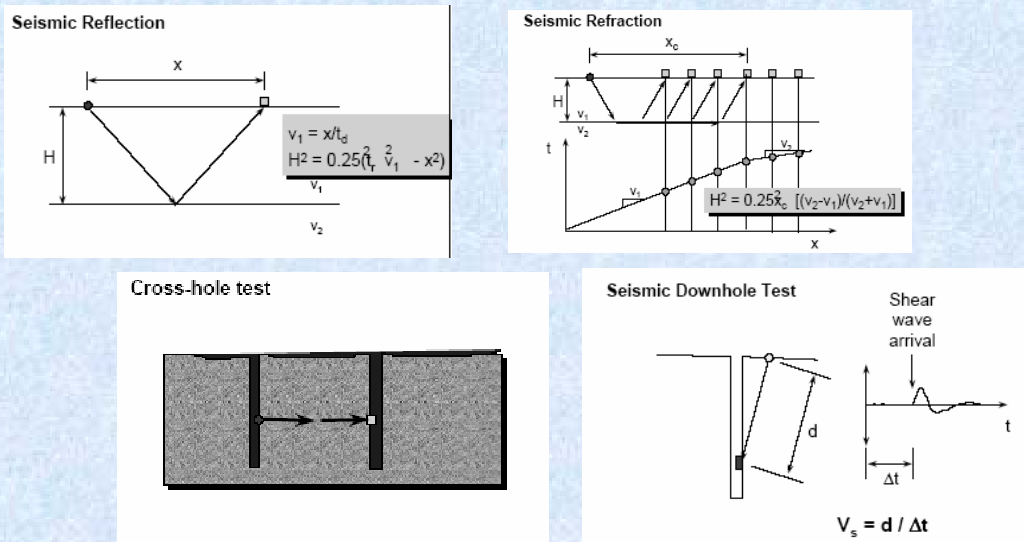
Viscoelastic parametres (weak deformation)

- Wave velocity : S, V_S ; and P: V_P
- Density : ρ
- Damping: ζ

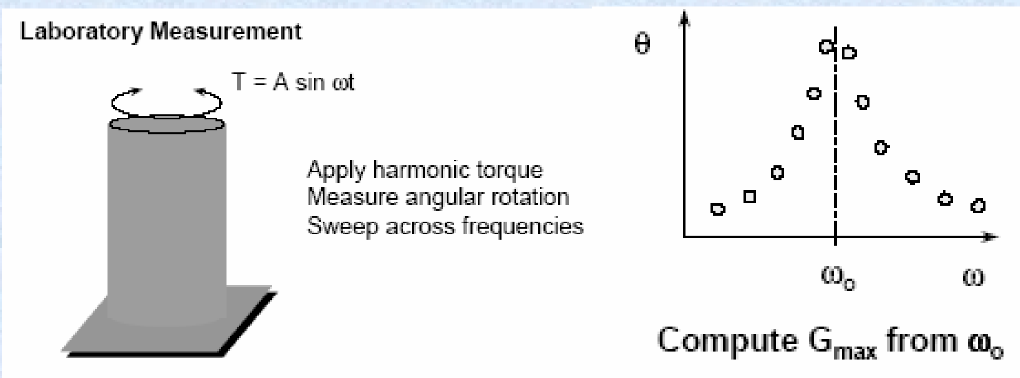
Non-linear parametres (large deformation)

- $G(\gamma)$ [i.e., $\beta(\gamma)$]
- $\zeta(\gamma)$

Method for Vs / Gmax

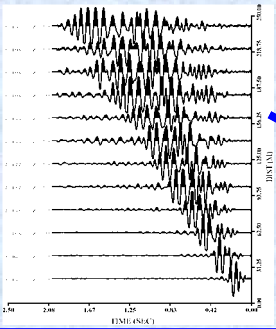


Method for Vs / Gmax : resonant column test

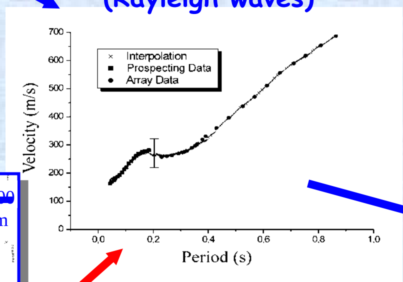


SASW and noise array techniques

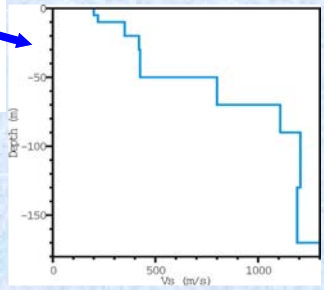
Active source (SASW)

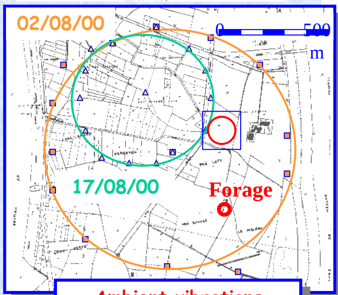


Dispersion curves
(Rayleigh waves)



Velocity profile





Ambient vibrations
(passive)

Methods for estimating the input parameters required by numerical modelling - 1

S wave velocity

	Method	Investigation depth Surface / Deep	Source Active / Passive	Cost Low-cost/ Expensive	Use easyness Easy / Standard / Non standard	Precision / Reliability Very high / Satisfactory / Unsatisfactory
Within Borehole	Cross-Hole	S	A	E	S	V
	Down-Hole	S, D	A	E	S	S
From the surface	Refraction	S, D	A	LC, E	S	S
	Reflexion	S, D	A	E	NS	S
	SASW	S	A	LC	S	S
	Microtremor, Array	S, D	P	LC	NS	S
Correlations	(SPT, Cu,)	S	-	LC	E	U

Methods for estimating the input parameters required by numerical modelling - 2

Geometry

	Investigation depth	Source	Cost	Use easyness	Precision / Reliability
Method	Surficial / Deep	Active / Passive	Low cost /Affordable/ Expensive	Easy / Standard / Non standard	Very high/ Satisfactory/ Unsatisfacory
Boreholes	S , D	-	A, E	E / S	V
Geology	S, D	-	LC	S	U
Gravimetry	D	(P)	LC, A	S	S
Seismic	S , D	A	A, E	S	S
H/V Noise	S, D	P	LC	E + NS	U (+ Vs)

Methods for estimating the input parameters required by numerical modelling - 3

NL Parameters + damping

Method		Investigation depth	Source	Cost	Use easyness	Precision / Reliability
		Surface / Deep	Active / Passive	Low cost/ Expensive	Easy / Standard / Non standard	High/ Satisfactory/ Unsatisfactory
Damping						
Borehole	Down-Hole	S, D	A	E	NS	S (HF)
Lab tests	Resonant column	S, [D]	-	E	S	S (HF)
Non-Linear Parameters						
Bore-Hole	Stations	S, D	Earth-quakes	E	NS	S
Lab tests	Triaxial	S, [D]	-	E	S	S
Correlations	(material)	S , D	-	LC	E	U

Other issues

? Until which depth

- 30m / 100 ft : insufficient for deep deposits

Non-linear parameters (large deformation)

- ? Frequency dependence
- ? Depth dependence

Sensitivity of numerical simulations

- Parameter uncertainty vs cost of numerical simulation
  - Damping and 2D/3D effects
  - High-frequency (short wave-length) / information density
  - NL

Estimation in site-specific studies

Standard, regulatory approach

Numerical approach

Instrumental approach

- From earthquake recordings (even weak motion)
- From microtremors / microseisms (partial information : f_0, more ?)

Instrumental approach : main methods

Objectives = spectral modifications (amplitude + phase)

Main methods

- Empirical attenuation relationships
  - Only amplitude
  - ? Not very site-specific
- Site / reference spectral ratios
  - Site-specific, but require earthqquake recordings
  - Good for amplitude
  - Phase : require a good signal / noise ratio
- H/V Techniques : single station estimates
  - Earthquake recordings : good for seismological networks
  - Noise : OK for f0 in case of large contrast
- Empirical Green's functions
  - Site specific
  - Do not account for NL behavior
- Dense array analyses
  - Very sophisticated, but provides rich, site-specific information
  - Noise : velocity profile + forward modelling

Site/reference spectral ratio technique

Instruments

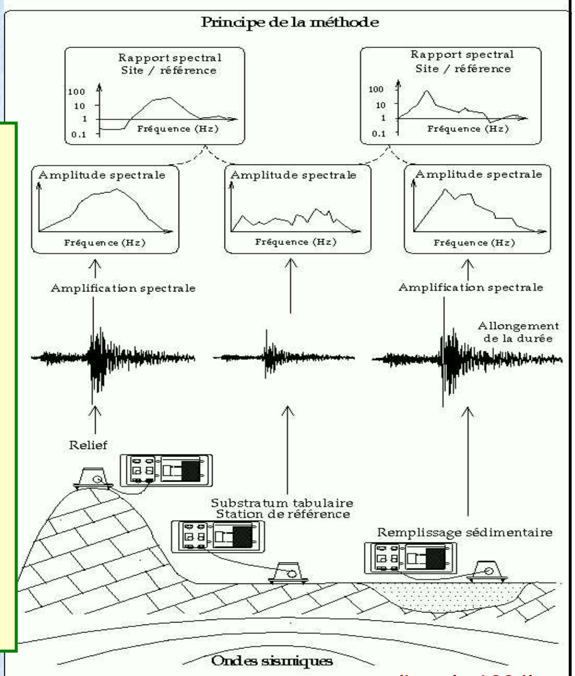
- pair of stations rock/site
- sensitive instruments
- frequency band 0.2 - 20 Hz
- (continuous recording)
- (permanent / temporary)

Recordings

- at least 10 pairs, several tens better
- S/N ratio (> 3)

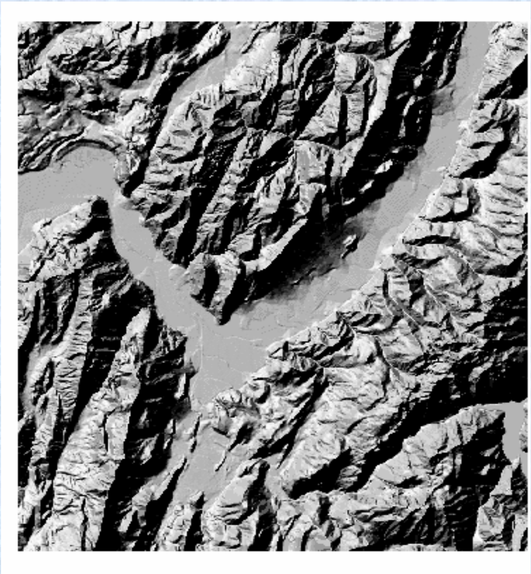
Ratios

- standard deviation ≈ 2



(Duval, 1994)

The Grenoble site



A glacial valley

- Young sediments (post glacial)
- Thick lacustrine deposits
- 2D / 3D geometry
- Very hard bedrock

Relatively recent urbanization

- XIX- XX
- Still rapidly expanding NE, NW, and S

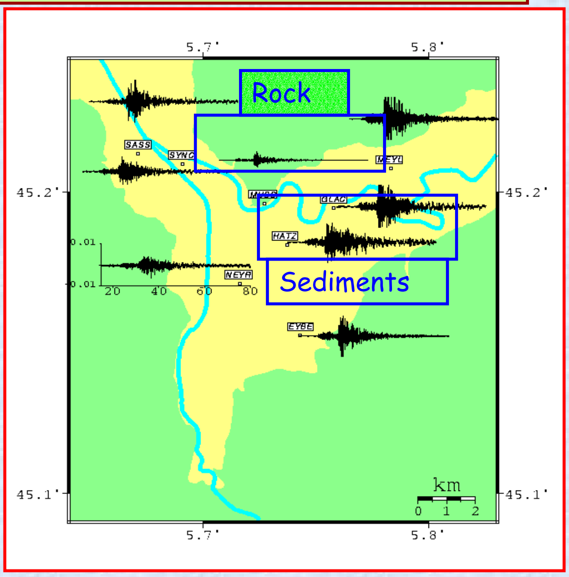
Typical recordings from local events

Event

- Baz = N10
- D=40 km, ML = 2.2
- EW Component

Observations

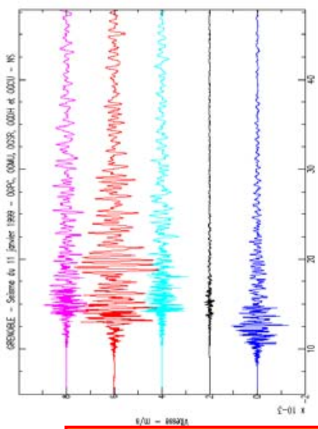
- Larger amplitude
- Longer duration
- Long duration for small events



Typical recordings from local events : permanent sensitive accelerometer local array

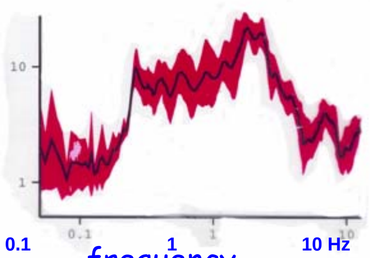
Event
- Baz = N180
- D=20 km, ML = 3.5
- EW Component

Observations
- Larger amplitude (x 5)
- Longer duration (x3)
- Long duration for a small event (15 s !)



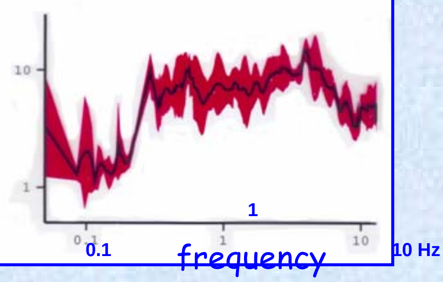
Experimental transfer functions

HATZ site



Average spectral ratio / rock

Campus site



Fundamental frequency = 0.25 Hz
Amplification band = 0.3 to 5 Hz
Amplification range = 8 to 20

Geometrical effects

Importance in alpine / mountainous context
Many other cases (Colfiorito, …)
Though, routine practice = 1D approach !

? How to know
about their existence
and importance ?

A proposal based on phase analysis : the mean group delay technique (Sawada, 1998)

(Beauval et al., 2001)

Seismic signal s(t)

→ $S(\omega) = A(\omega) \cdot e^{-\iota\varphi(\omega)}$

$A(\omega)$ = ***Modulus***

controls the amplitude

$\varphi(\omega)$ = ***Phase :*** ***controls the time domain envelope***

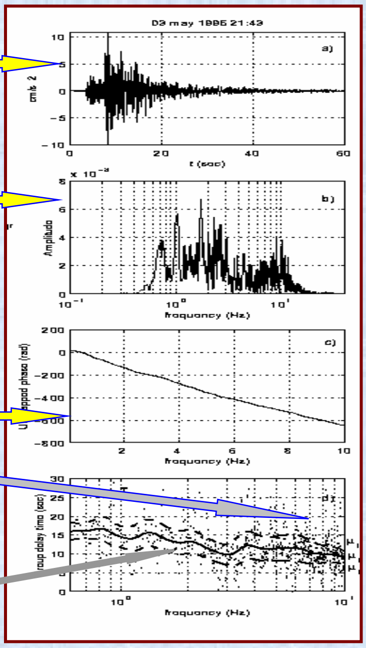
a) phase unwrapping

b) Derivation $T_{gr}(\omega) = \partial\varphi / \partial\omega$

c) smoothing

$\mu(\omega_0) = \int L(\omega,\omega_0) \cdot T_{gr}(\omega) \cdot d\omega$

(smoothing window)



(Beauval et al., 2001)

Site-specific duration increase

Classical decomposition : *source / propagation / site*

$s(t) = f(t)*p(t)*l(t) \longrightarrow S(\omega) = F(\omega) \,.\, P(\omega) \,.\, L(\omega)$

Modulus

$A_S(\omega) = A_F(\omega) \,.\, A_P(\omega) \,.\, A_L(\omega)$

Amplitude ratio

$A_L(\omega) = A_S(\omega) / A_R(\omega)$

Phase and group delay

$\varphi_S(\omega) = \varphi_F(\omega) + \varphi_P(\omega) + \varphi_L(\omega)$

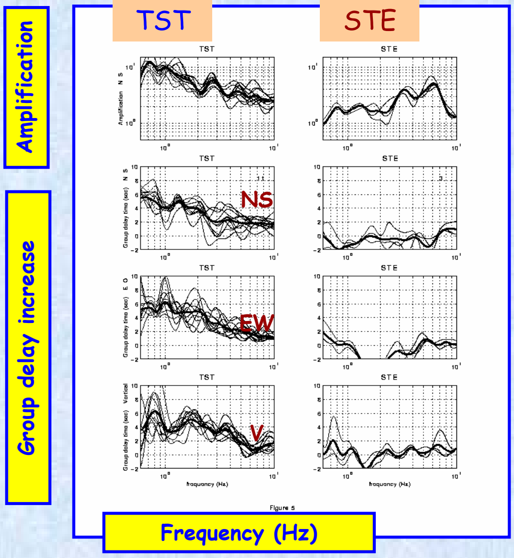
$T^L{}_{gr}(\omega) = T^L{}_{gr}(\omega) + T^L{}_{gr}(\omega) + T^L{}_{gr}(\omega)$

$\mu_S(\omega) = \mu_F(\omega) + \mu_P(\omega) + \mu_L(\omega)$

Group delay increase

$\mu_L(\omega) = \mu_S(\omega) - \mu_R(\omega)$

A stable measurement of duration increase



Observations

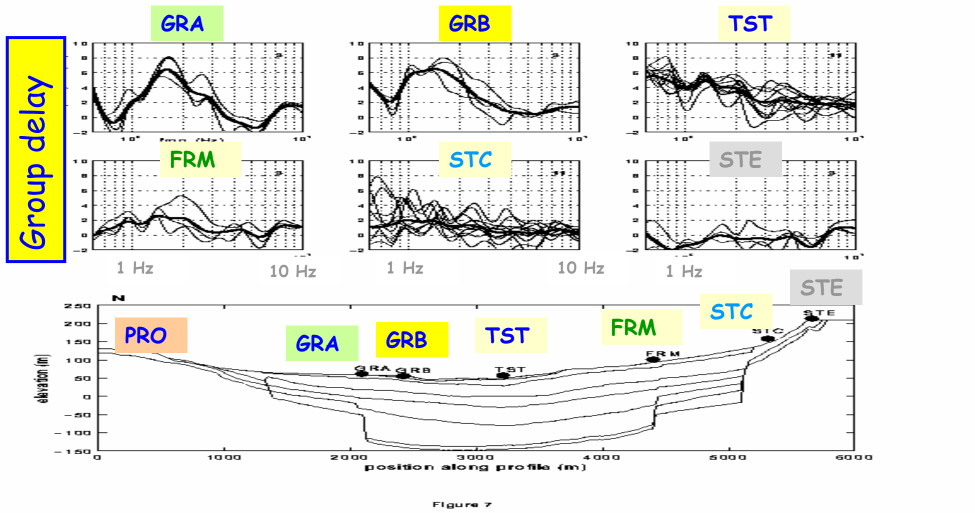
Stability of group delay increase

- whatever the event
- whatever the component

Consistency with amplification crurve

- Maximum group delay increase at the fundamental frequency
- No increase on rock

An example in the Volvi area



(Beauval et al., 2001)

H/V techniques

Smoothed Fourier spectrum (H) / Smoothed Fourier spectrum (V)

- Noise or earthquake recordings
- Simple
- Single station
- Robust

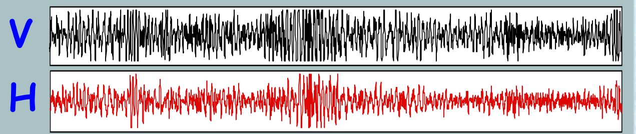
What does it mean ?????

- Eq recordings : Ratio of S to P wave transfer functions (?)
  - identifies only the fundamental frequency
    - another argument for systematic site instrumentation
    - allows to detect very simply the existence of site effects
  - ? corresponding amplification : not so good correlations
- Noise recordings :
  - Rayleigh wave ellipticity + Love wave Airy phase + S wave resonance
  - identifies only the fundamental frequency
  - does not measure the corresponding amplification

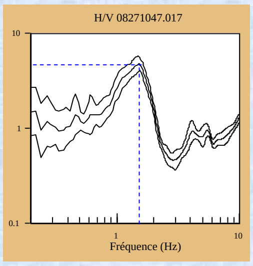
  - (possibility to invert the velocity profile : may be, under some conditions)

H/V on noise recordings

Noise recording



H/V spectral ratio (generally) allows to identify the fundamental frequency



(Chatelain, 2003)

Noise measurements and site effects

(Kanai : index)

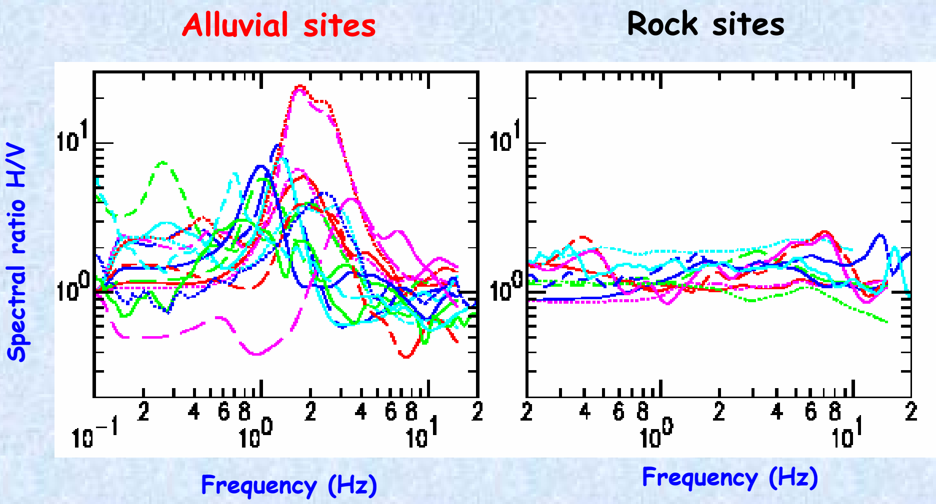
Predominant frequency

Site / reference

H/V

Array

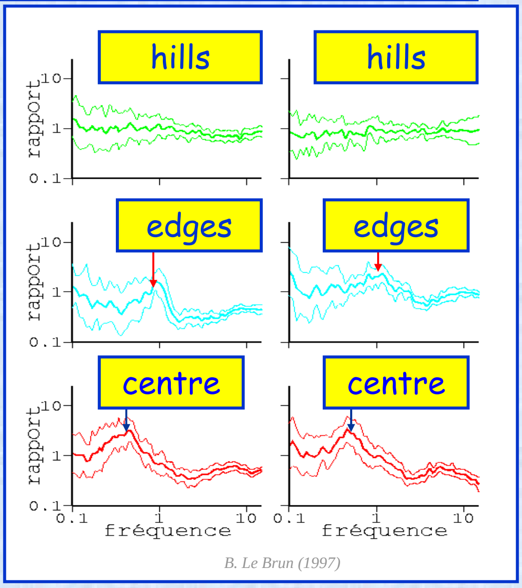
Example H/V curves



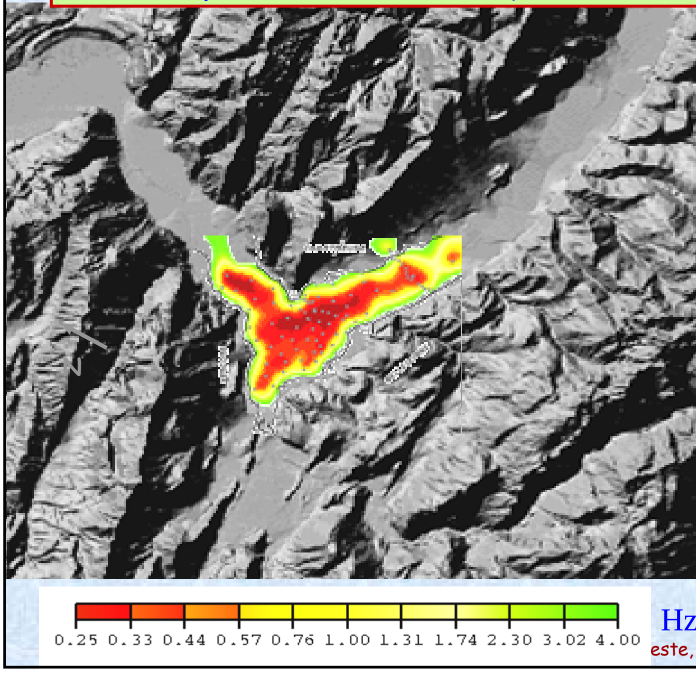
An example application : Grenoble (Lebrun et al., 2001)

H/V processing

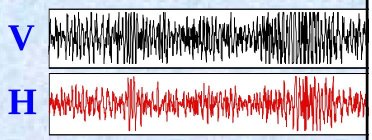
- (long windows, broad band sensors)
- Low frequency
- Consistent results

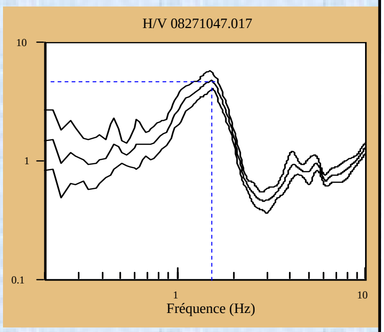


Example : resonance frequencies in the Grenoble basin



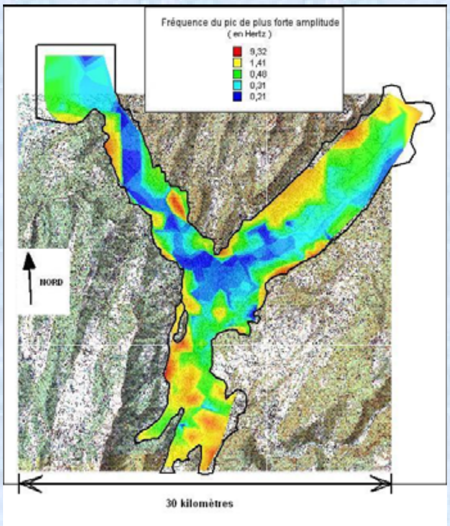
Hz





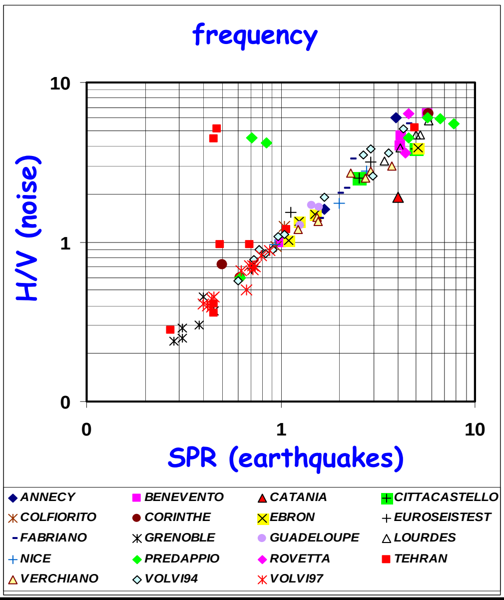
Lebrun, Bard et Hatzfeld, 1997
J.L. Chatelain

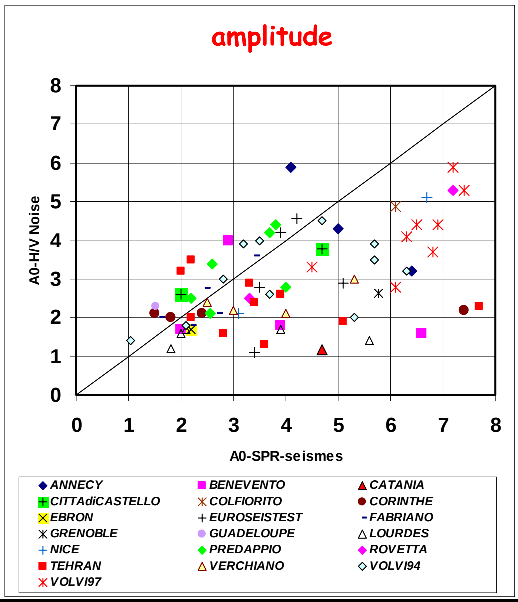
Resonance frequency from H/V



Banton et Guéguen, 2004

H/V noise vs Site/Reference spectral ratio





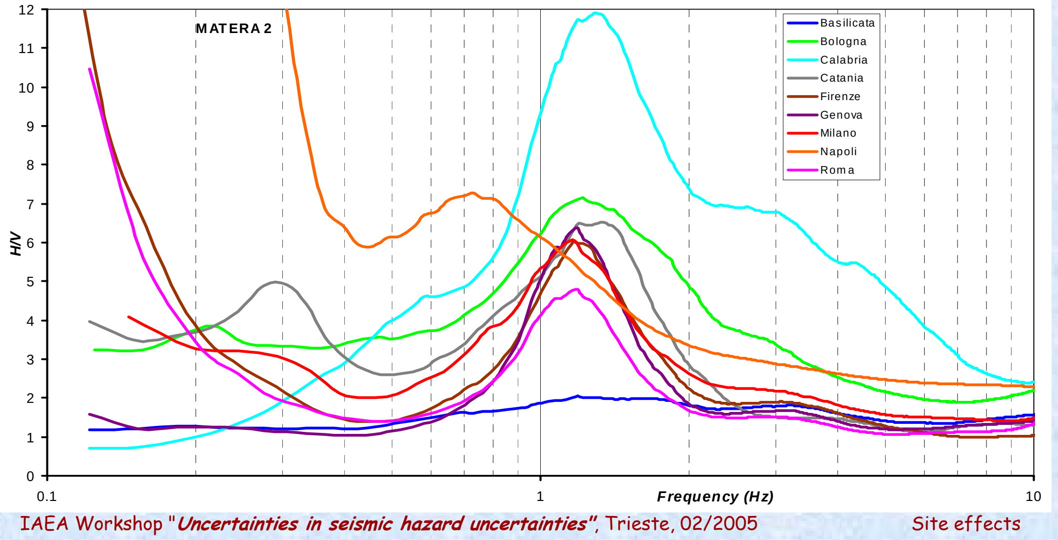
Need for H/V standardization : Examples from Italy

Several sites
Measurements with different instruments
Processing with different softwares

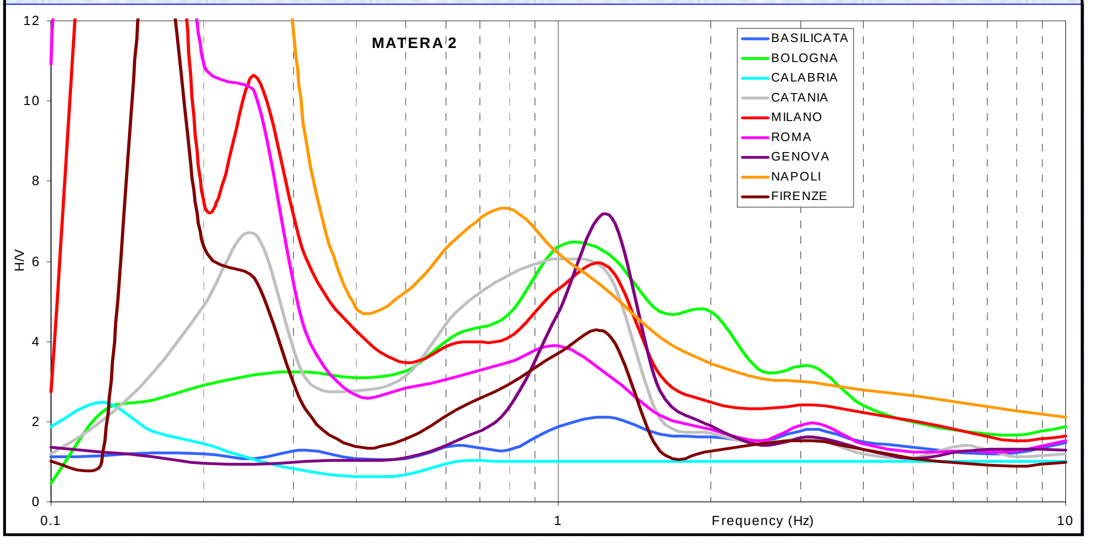
(Courtesy M. Mucciarelli)

Site 2 - >100 m of clay above limestone

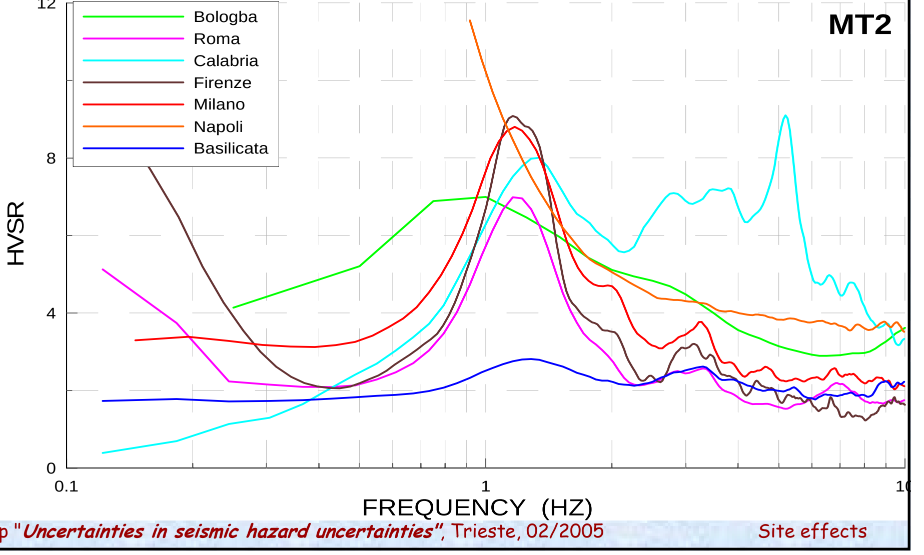
Site 2
Processing 1



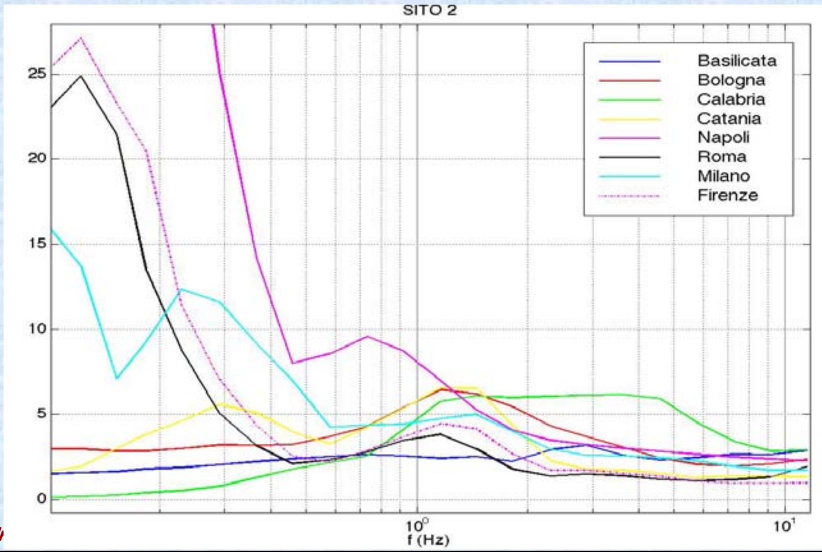
Site 2
Processing 2



Site 2
Processing 3

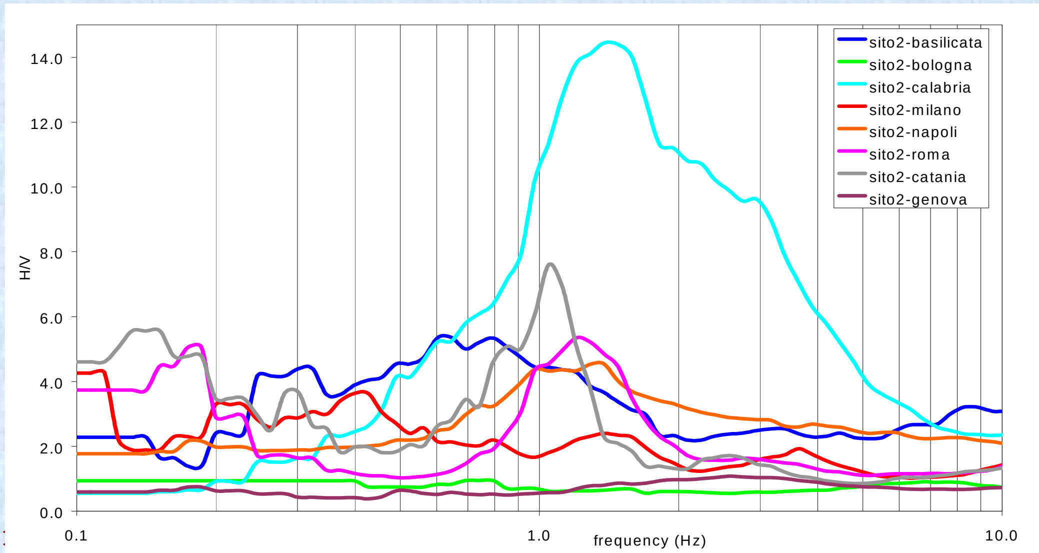


Site 2
Processing 4



IAEA Workshop "U

Site 2
Processing 5



THE SESAME PROJECT : AN OVERVIEW AND MAIN RESULTS

Site Effects aSsessment using AMbient Excitations

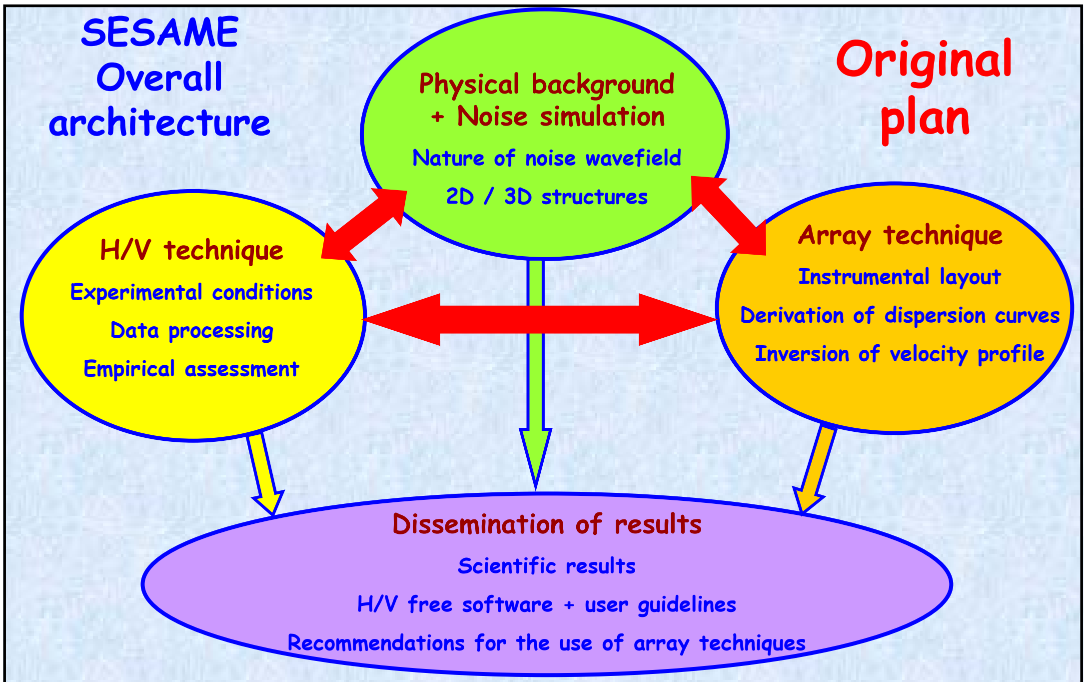
An EC / ESD project
(May 1, 2001 – October 31, 2004)

University Bergen
Institute of Geophysics Bratislava
Resonance Geneva
LGIT/LCPC Grenoble
University Liège / LIRIGM Grenoble
University Lisboa
CNR Milano
CETE Nice
University Potsdam
INGV Roma
ITSAK Thessaloniki
ETH Zürich

http://SESAME-FP5.obs.ujf-grenoble.fr

SESAME Overall architecture

Original plan



H/V technique

Experimental issues

Instruments and sensors

- Velocimeters, accelerometers

Field conditions

- Soil-sensor coupling
- Weather…

Processing issues

Processing

- Window selection, smoothing, …

Platform-free Software

- Browsing / GUI / Main processing module

Alternatives

- Extraction of Rayleigh wavelets

Experimental assessment

Thorough comparison with site to reference spectral ratios

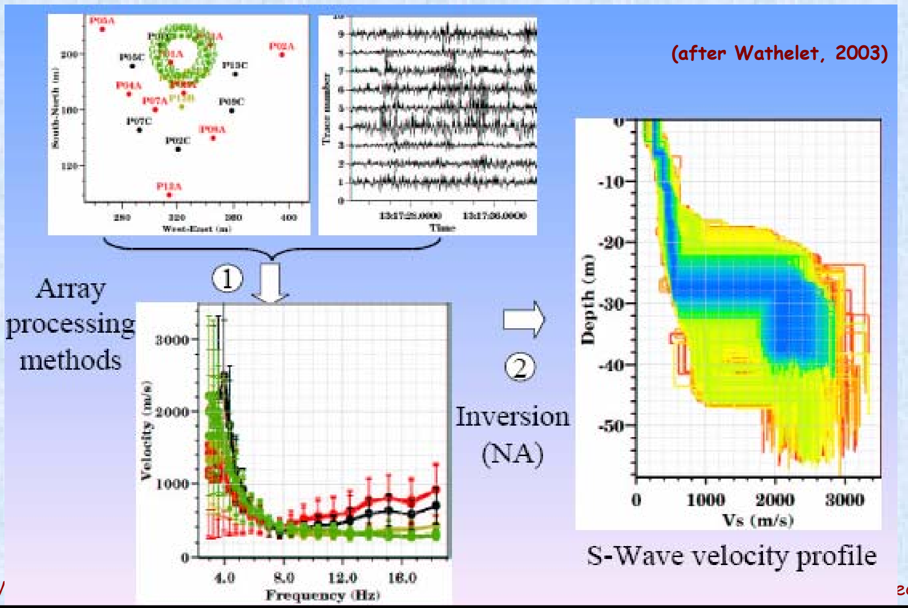
[More than 150 sites]

Direct comparison with damage observations

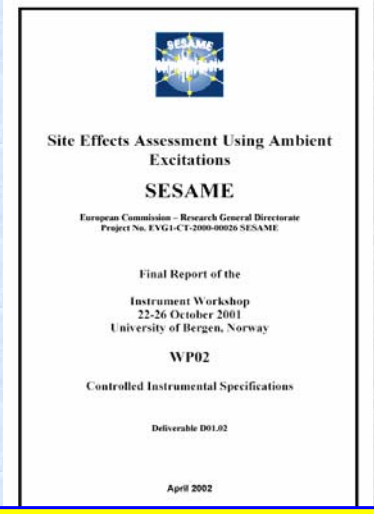
Numerical assessment

1D, 2D and 3D structures

Principle of array techniques



Deliverables


Site Effects Assessment Using Ambient Excitations

SESAME

European Commission – Research General Directorate
Project No. EVG1-CT-2000-00026 SESAME

Final Report of the

Instrument Workshop
22-26 October 2001
University of Bergen, Norway

WP02

Controlled Instrumental Specifications

Deliverable D01.02

April 2002


Site Effects Assessment Using Ambient Excitations

SESAME

European Commission – Research General Directorate
Project No. EVG1-CT-2000-00026 SESAME

Final Report

WP09

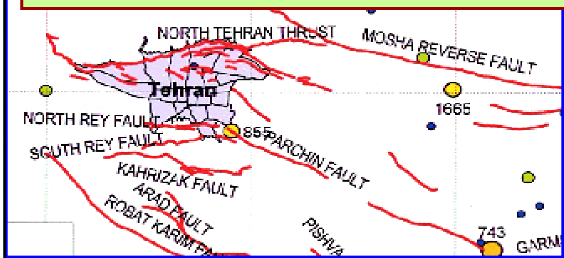
FD code to generate noise synthetic

Deliverable D02.09

April 2002

All deliverables on http://SESAME-FP5.obs.ujf-grenoble.fr

Estimation methods : The case of Tehran, an instructive example

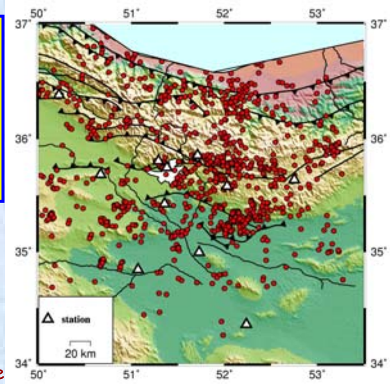


Threat : M7+

M6 inside the city ?

1996-2000

IGTU
Hatzfeld



Microzonation and site effect studies in Tehran

Previous studies :

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

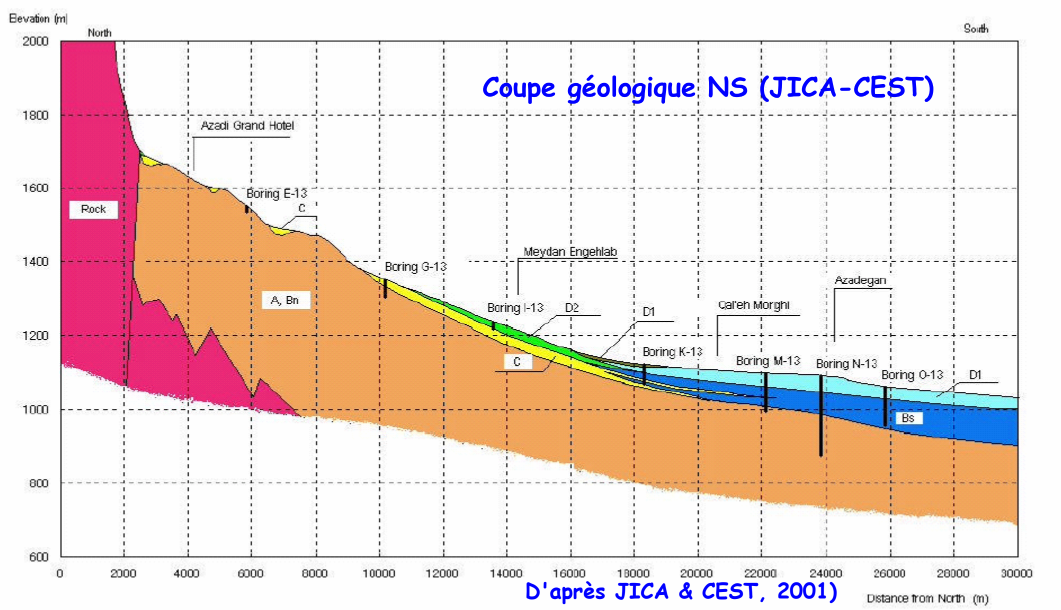
Contents

- 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

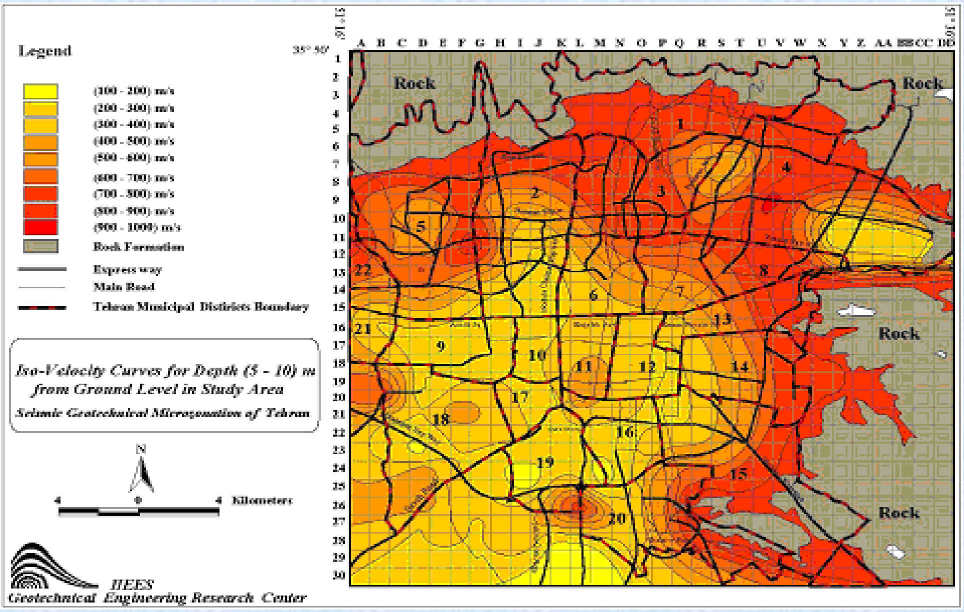
- Stiff and "shallow" deposits in the North
- Softer and thicker deposits in the South
- Moderate amplification (<2) only at intermediate and high frequencies (f>1-2 Hz)

NS Tentative cross-section

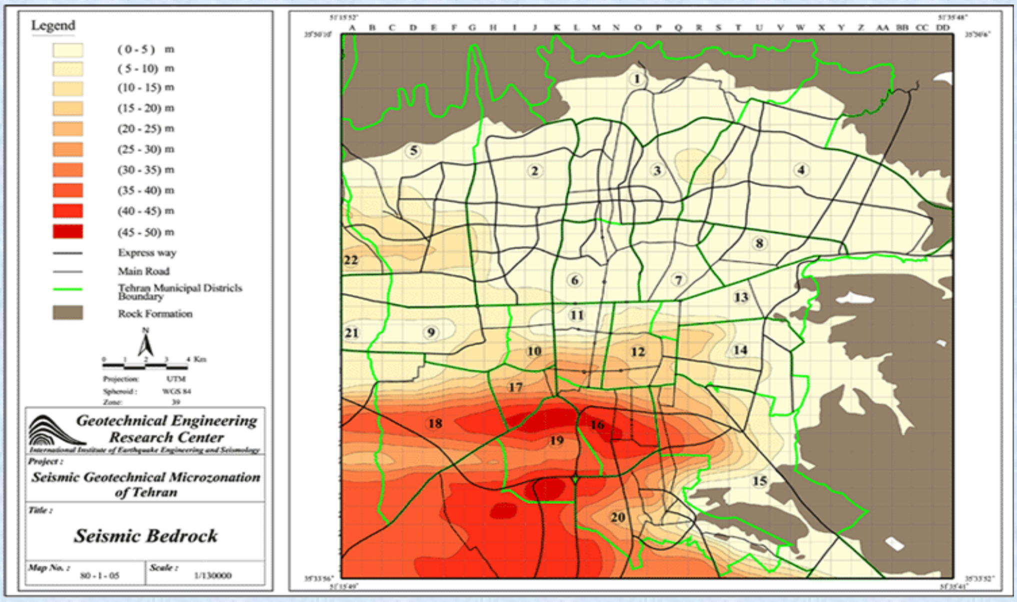


D'après JICA & CEST, 2001)

SURFACE VELOCITY MAP (IIEES)



DEPTH TO "SEISMIC BEDROCK" (IIEES) [Vs > 600-700 m/s)



Soil columns

Maximum thickness above "seismic bedrock" : 150 m

Maximum thickness of soft deposits (N = 15) : 30 m

Model No.	Depth (GL-m)																									
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120	130	140	150	
1	C1	C1	C1	C1	C1	C1	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
2	C1	C1	C2	C2	C2	C2	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
3	C1	C1	CS1	CS1	CS1	CS1	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
4	C1	C1	C2	C2	C2	C2	C2	C2	C2	C2	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
5	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
6	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS3	C2	C2	C2	C2	C2	C2	C2	C2	C2	C4
7	C1	C1	C2	C2	C2	C2	C2	C2	C2	C2	C3	C3	C3	C3	C4											
8	C1	C1	C2	C2	C2	C2	CS2	CS2	CS2	CS2	CS3	CS3	CS3	CS3	C4											
9	C2	C2	CS2	CS2	CS2	CS2	C3	C3	C3	C3	C2	C2	C2	C2	C4											
10	C1	C1	CS2	CS2	CS2	CS2	C3	C3	C3	C3	C2	C2	C2	C2	C4											
11	C2	C2	C3	C3	C3	C3	CS3	CS3	CS3	CS3	C2	C2	C2	C2	C4											
12	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C4															
13	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
14	C2	C2	C2	C2	C2	C2	CS2	CS2	CS2	CS2	CS4															
15	CS1	CS1	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
16	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
17	C2	C2	CS1	CS1	CS1	CS1	CS3	CS3	CS3	CS3	CS4															
18	G2	G2	CS1	CS1	CS1	CS1	G3	G3	G3	G3	G4															
19	C3	C3	C3	C3	C3	C3	G3	G3	G3	G3	G4															
20	C2	C2	C3	C3	C3	C3	CS3	CS3	CS3	CS3	CS4															
21	CS2	CS2	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS4															
22	C1	C1	C1	C1	C1	C1	C4																			
23	C2	C2	C2	C2	C2	C2	C4																			
24	CS2	CS2	CS2	CS2	CS2	CS2	CS4																			
25	C1	C1	CS2	CS2	CS2	CS2	CS4																			
26	CS1	CS1	CS3	CS3	CS3	CS3	CS4																			
27	G2	G2	G4	G4	G3	G3	G4																			
28	C2	C2	G3	G3	G3	G4																				
29	S3	S3	S3	S3	S3	G4																				
30	S3	S3	G3	G3	G3	G4																				
31	G3	G3	G3	G3	G3	G4																				
32	G2	G2	G3	G3	G4																					
33	G3	G3	G3	G3	G4																					
34	G3	G3	G3	G4																						
35	S3	S3	S3	G4																						
36	CS3	CS3	CS3	G4																						
37	C1	C1	C1	G4																						
38	C2	C2	C2	G4																						
39	G3	G3	G4																							
40	Pre-Miocene																									
41	Rock																									

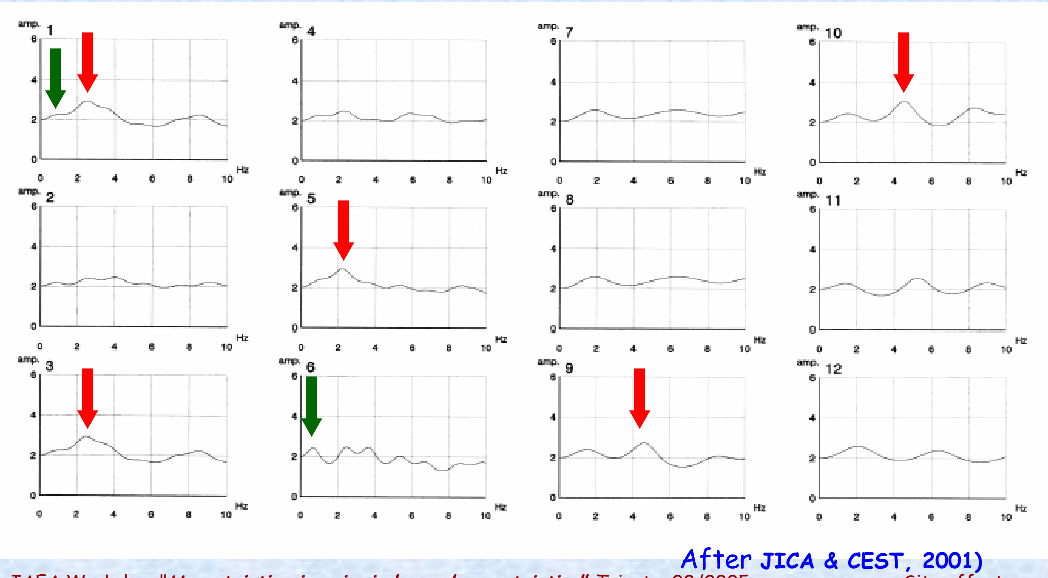
Soil Name, Symbol and N Value

Clay	C1	C2	C3	C4
Average N Value	15	35	75	100
Sand and Clay	CS1	CS2	CS3	CS4
Average N Value	15	35	75	100
Sand	S1	S2	S3	S4
Average N Value	15	35	75	100
Gravel	G1	G2	G3	G4
Average N Value	15	35	75	100

G4 — Engineering seismic bedrock and its soil type

After JICA & CEST, 2001)

Estimated 1D Fourier transfer functions



After JICA & CEST, 2001)

H/V and 1D results

Only very moderate amplification (< 2) for f ∈ [2 – 10 Hz]

No effects at low frequency

Present study:

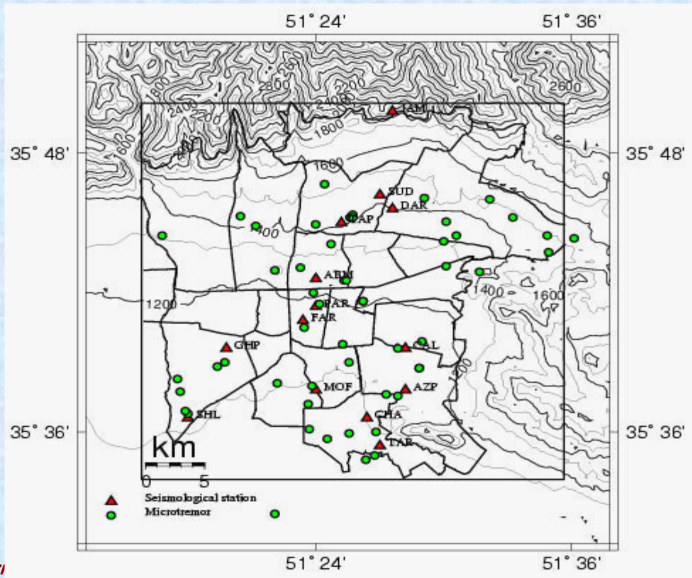
Based on a temporary seismological survey

13 seismological stations, Feb - June 2002

(2 Rock references)

60 seismic noise measurements

(to guide the interpolation of SR)



Over one hundred recorded events

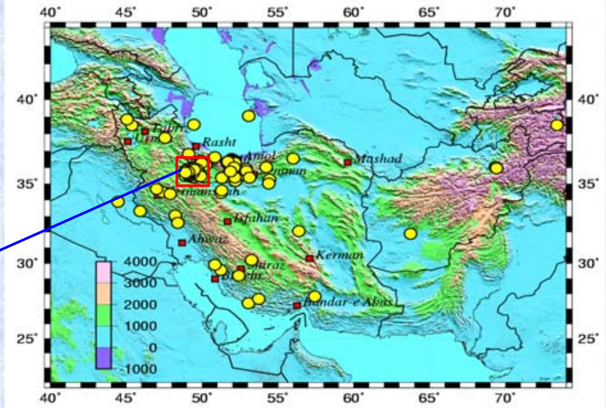
(regional + teleseismic)

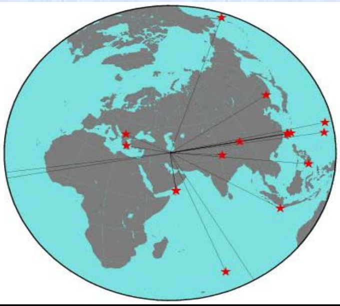
Changureh-Avaj event

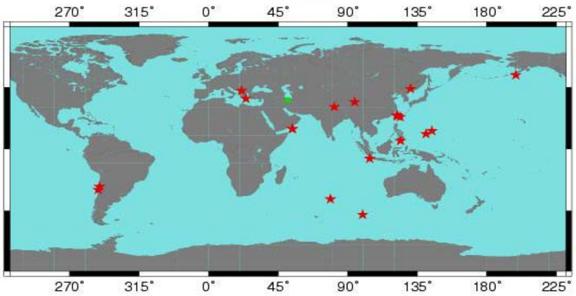
2002/06/22

Magnitude: 6.3

225 Km west of Tehran







Processing / Analysis

Time domain

- Peak values (Ex. Avaj : pga from 4 to 23 cm/s²)
- (duration)

Frequency domain

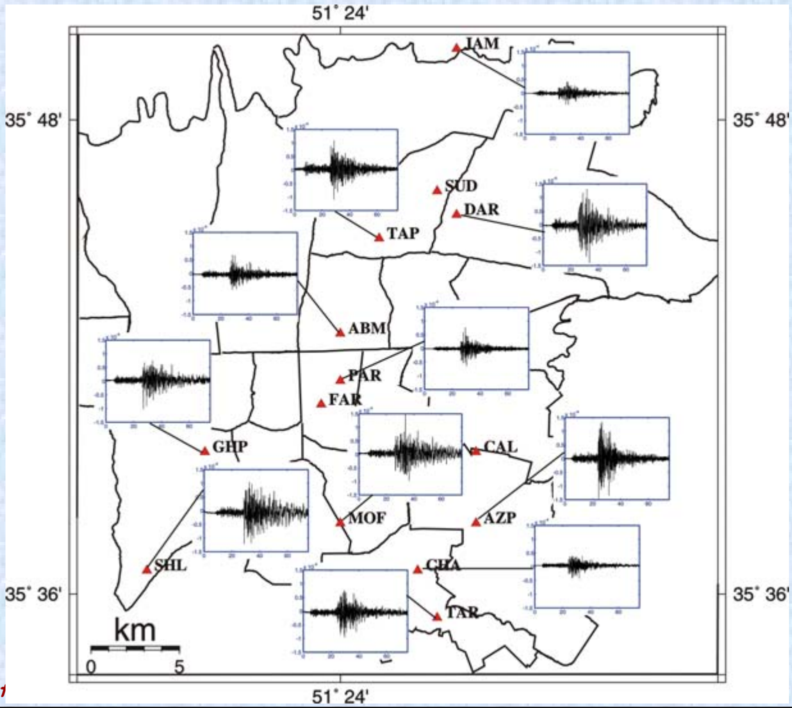
- Ambient noise recordings (H/V)
- Earthquake recordings
  - H/V
  - Site to reference spectral ratios
  - Frequency dependent lengthening (group delay analysis)

} Long windows (P + S), SNR >3

Strong motion prediction with EGF technique

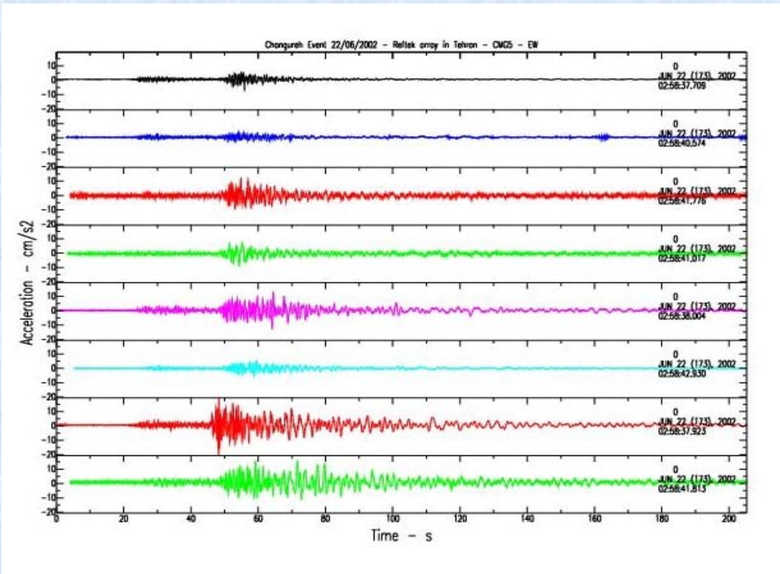
- First step : tests on AVAJ sequence
- Other (Mosha, …)

NS Component, Semnan event
(05/05/2002, M=4)



CHANGUREH EVENT, 22/06/2002 : EW ACCELERATION TRACES

JAM
CHA
TAP
ABM
FAR
CAL
SHL
MOF



PGA

from

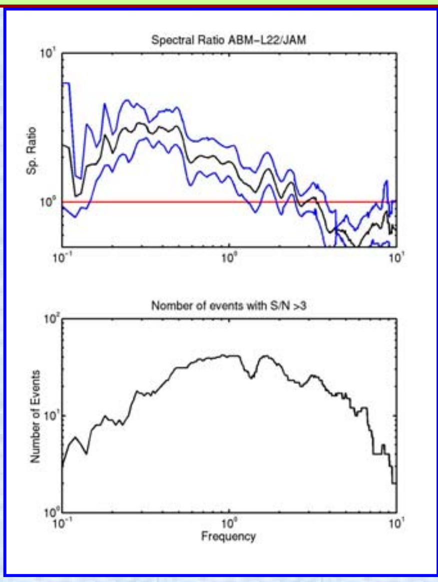
4 cm/s²

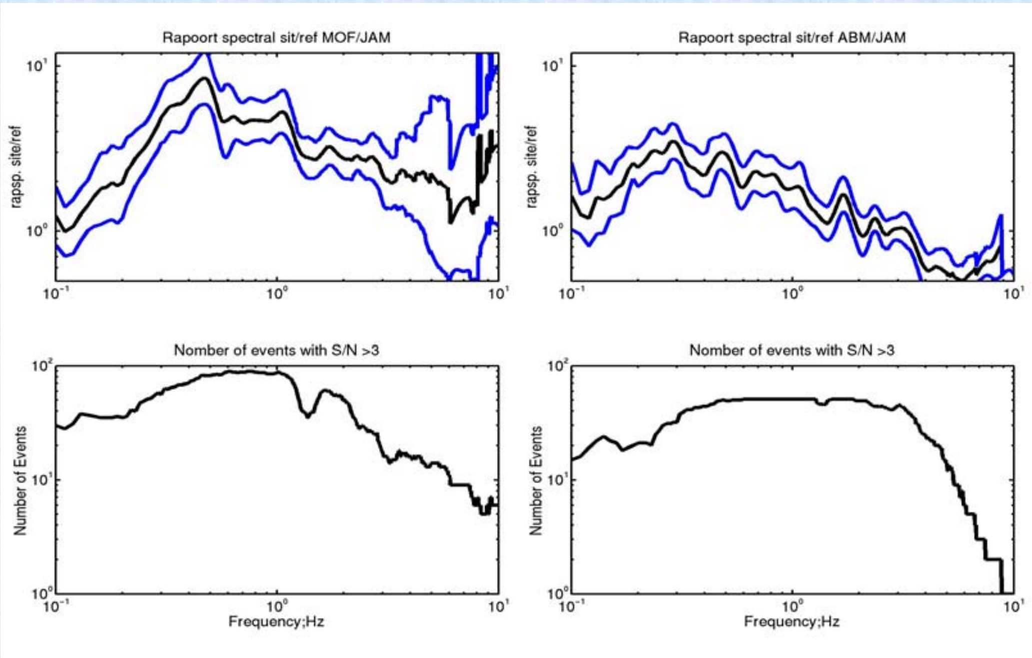
to

23 cm/s²

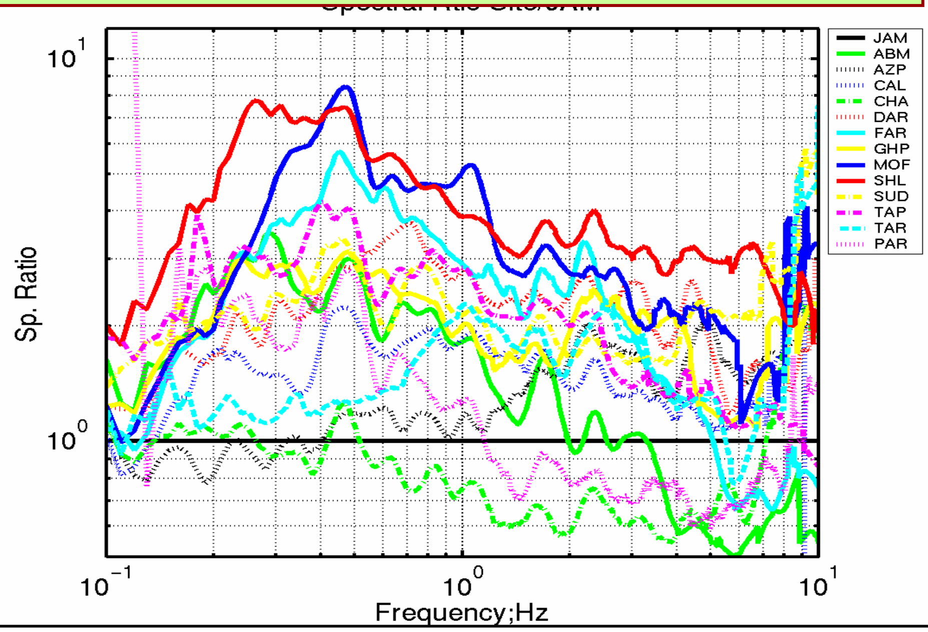
Site / Reference spectral ratios

Site	/ JAM	/CHA
JAM	128	55
SUD	33	33
DAR	45	17
TAP	29	27
ABM	51	25
PAR	(0)	(0)
FAR	41	14
GHP	40	24
CAL	56	30
AZP	54	27
MOF	91	46
CHA	55	55
SHL	73	44
TAR	45	20

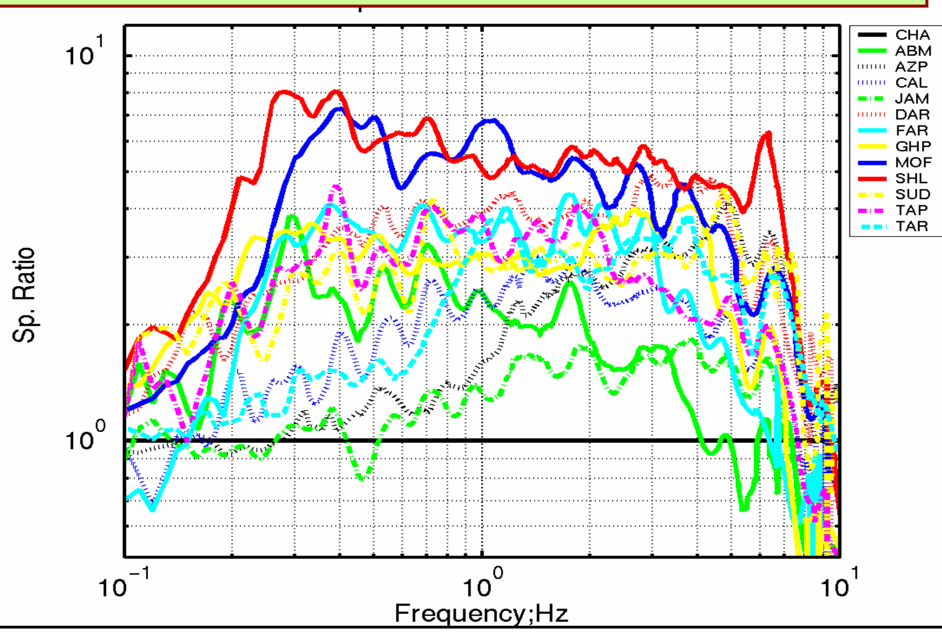




Measured spectral amplifications in Tehran
(ref = JAM)



Measured spectral amplifications in Tehran
(ref = CHA)

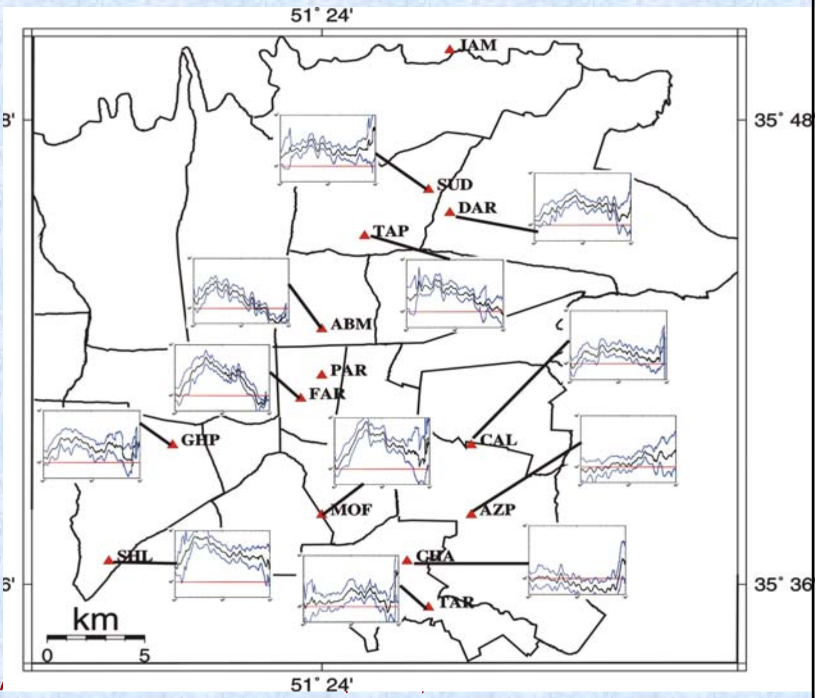


Tehran :

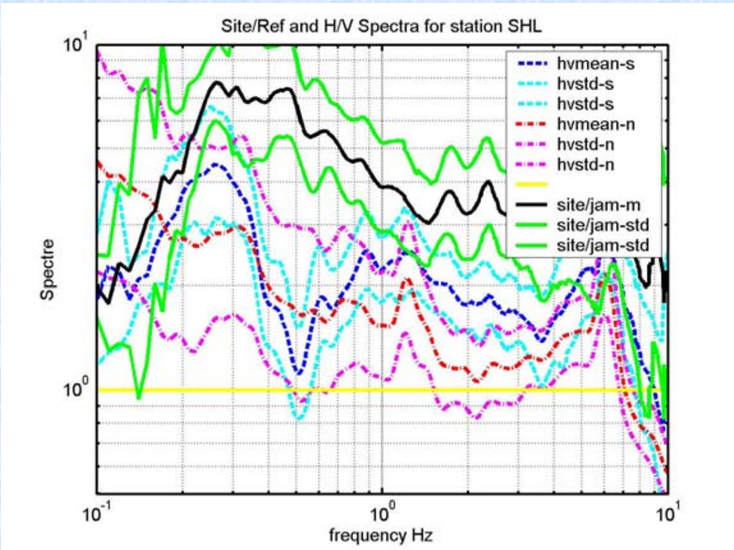
Observed amplifications

Increase from NE to SW

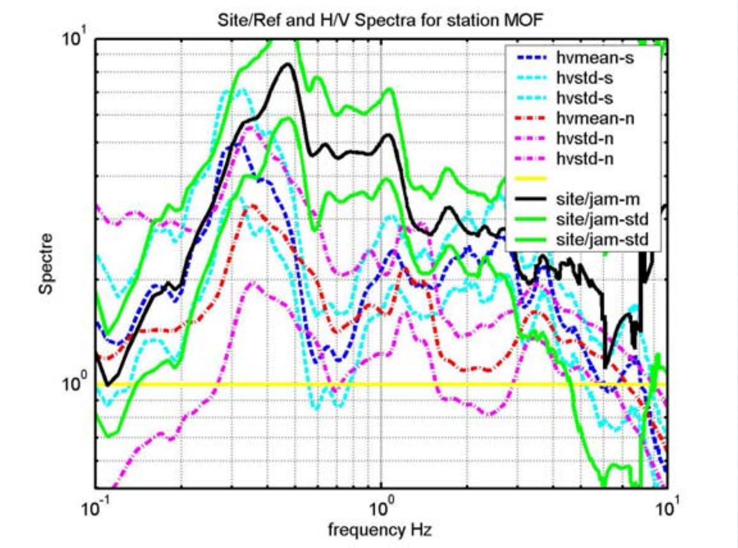
Broad-band everywhere, except in SE (TAR, AZP, CAL)



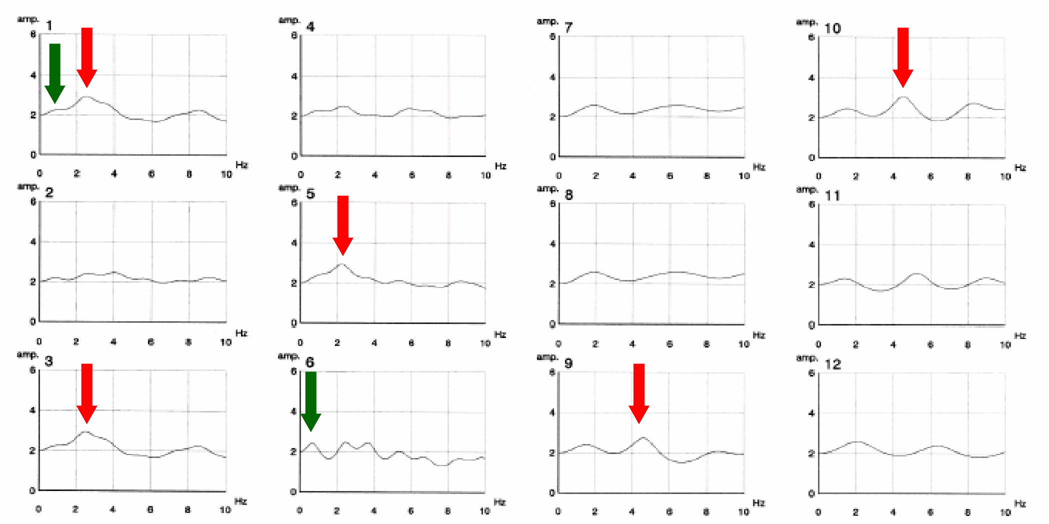
SHL



MOF



Estimated 1D Fourier transfer functions



After JICA & CEST, 2001)

Groupe delay lengthening : application to the Tehran area

Selection of events with good signal to noise ratios

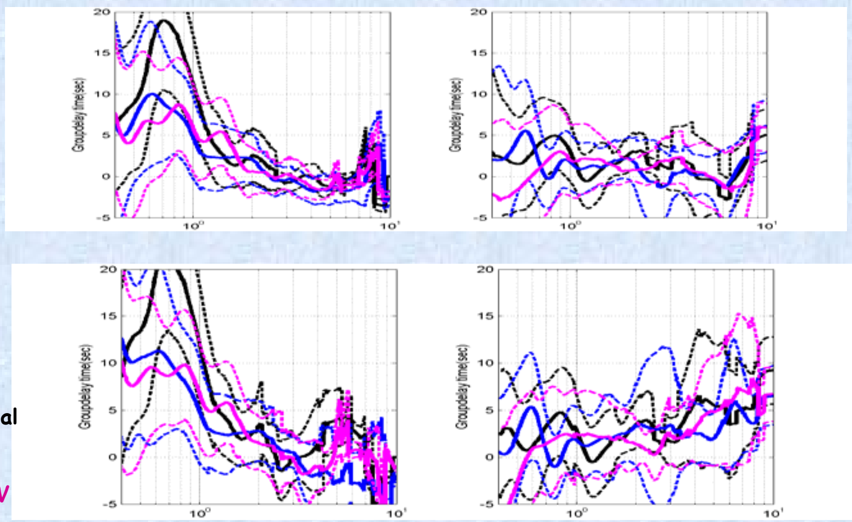
Analysis of group delay variations

- Padding with zeros (phase unwrapping)
- Averaging over many events

SHL SUD

Np=8192

Np=16384



Black=vertical

Blue=NS

Magenta=EW

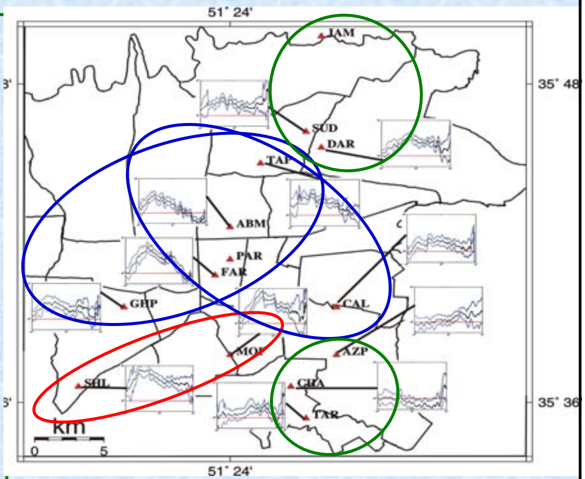
Conclusions on duration

Large standard deviations but

Larger low frequency lengthening > 10 s
- SHL, MOF

Intermediate lengthening : 5 to 10 s
- GHP, FAR, ABM, TAP, CAL

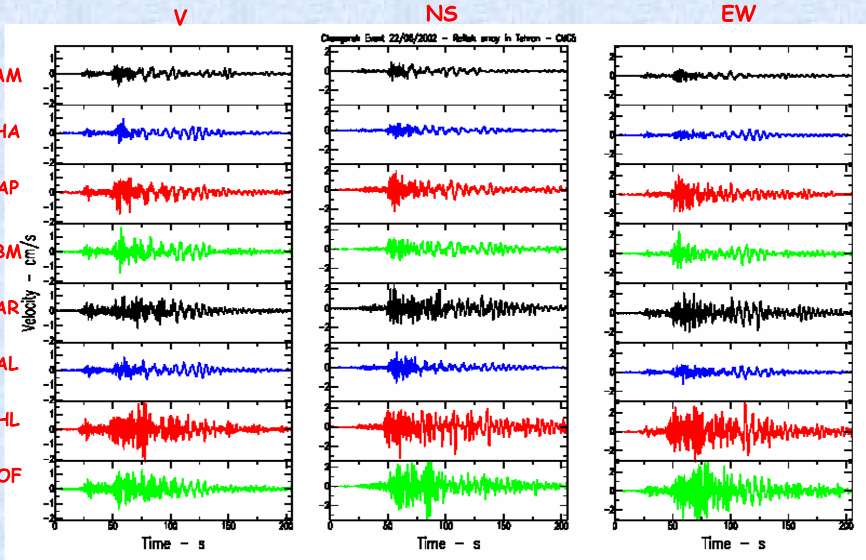
Small lengthening : < 5 s
- SUD, DAR, AZP, TAR, CHA



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

V NS EW

JAM
CHA
TAP
ABM
FAR
CAL
SHL
MOF



North (1 cm/s)

South (3 cm/s)

Possible explanations

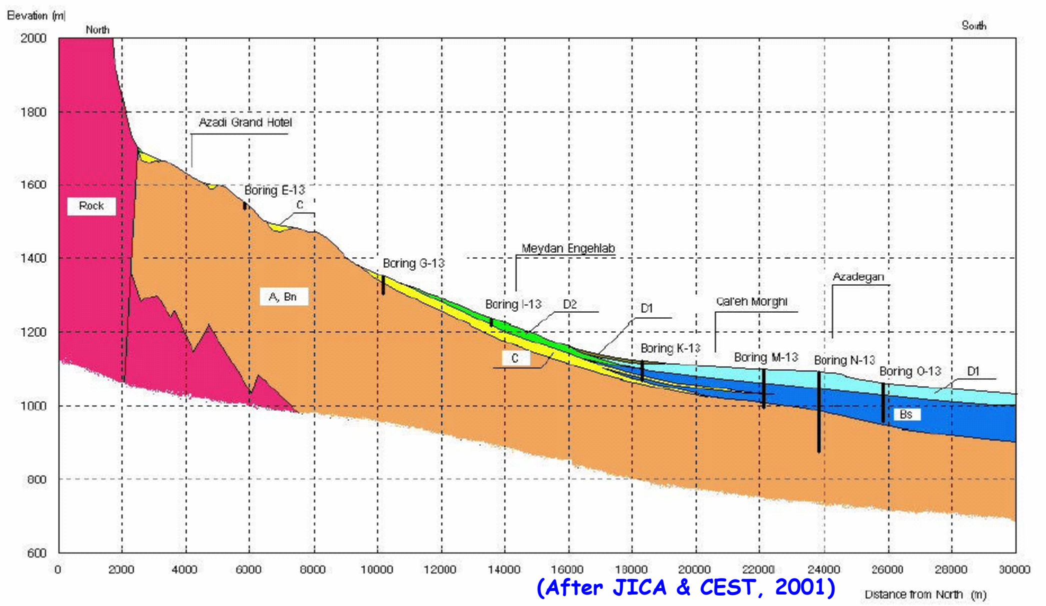
Low frequency effects

- Very soft material
  - Absent in northern Tehran
- Or very thick, stiff deposits underlain by very hard bedrock
- Or thin soft layer under stiff thick deposits

Potential structures

- Thick stiff "A" layer + North-Tehran fault
- Old (big) river channel
  - ?? "deep" structure under Tehran ??

Geological cross-section NS (JICA-CEST)



(After JICA & CEST, 2001)

Conclusions on estimation methods

Numerical approach
- Require detailed and redundant geotechnical and geophysical surveys
- Sensitivity analysis : mandatory

Empirical attenuation relationships
- Very badly constrained (usually)
- Smoothing and under-differentiation by mixing different sites

Usefulness and interests of specific instrumental measurements
- Calibrating the models in the weak motion range
- Possibility to reconstruct directly site specific time histories
- Interest and limitations of H/V techniques
- Interest of dense arrays for peculiar sites

Need for knowledge improvement on NL behavior
- Extrapolation of weak motion estimates
- ? Reliability of empirical coefficients ?
- Measurement of soil NL characteristics

Conclusions / recommandations
- Importance of an instrumental calibration

Overview

Introduction on site effects
- ground shaking / induced
- Examples and order of magnitude

Physical Phenomena
- Surface topography
- Alluvial / sedimentary cover

Estimation methods
- Non-site specific techniques
  - GMPE
- Site specific methods
  - Numerical approach
  - Instrumental approach

Concluding comments
- Site effects
- Uncertainties

CONCLUSIONS

Importance of local site conditions

Amplification / resonance (soft alluvial cover / surface topography)
(+ Liquefaction and Landslides : > 20 % of overall death toll)

Site effect in Regulations (usual buildings)

- Requires a minimum geotechnical information !
- Recent / new regulations (UBC97 / EC8)
  - increasing site factors and spectral differences
- Non-site specific: may be dangerous for "non-standard" sites

Site-specific studies

- Require a (larger) minimum geotechnical information !
- Value of instrumental approach : Should be mandatory !
- Numerical approach: very appealing !
  - Easyness, apparent low-cost (1D)
  - may be highly misleading

Identify the possibilities of peculiar effects

Site specific estimates

Ideal case

- **Good knowledge of the site geology and parameters**
  - Nature and Geometry of the different geotechnical units, i
  - Vs(i), Qs(i)
- **Response calculation**
  - Simple 1D modelling
    - Linear
    - Linear equivalent G(γ) – D(γ)
    - Truly Non-linear (not so simple…)
  - More advanced 2D or 3D modelling
    - Linear
    - (Non-linear)

Site effect estimation

Usual case : nothing, or only very little, is known !

- Site classification according to building code
- Estimation of Vs and h: T = 4h / Vs
- Simple 1D computations
- Instrumental measurements
  - Soil period : noise measurements
  - Recording of (weak) earthquakes

    Issue: no non-linearity !

    ? Usefulness and relevancy for strong events ?
- Identification of typical, potentially dangerous, configurations
  - Surface topography, valley, basin, strong lateral heterogeneity

Recommendations / Propositions

Detecting the existence of site effects

- Systematic measurements of noise + careful (standardized) H/V processing
- Permanent, sensitive instrumentation
  - Site / rock reference pair : a minimum
    - reference rock: preferably on outcropping surface rock
    - Vertical arrays welcome
  - Sensitive (broad band : 5s - 20 Hz): to accumulate data with high S/N ratio as quickly as possible

    (→ Model calibration, synthetics with realistic phase, …)

  ! Should be mandatory !

Geotechnical measurements : Vs(z)

- borehole measurements (cross-hole, down-hole, …)
- from surface (reflexion / refraction, SASW, noise array, …)

Peculiar sites

- Very dense surface array (at least for 6 months)

Uncertainties in site effects knowledge

Lack of knowledge / lack of data

- Surface topography
- Non-linearities
  - Close the gap between seismologists and geotechnical engineers
- Actual, quantitative site characteristics of SM stations
- Relevancy of decoupling source and site effects

Lack of affordable/available survey techniques

- Thick deposits
- In-situ measurements for damping
- In-situ measurements of NL characteristics

Lack of exchanges academic world ←→ engineering world

- 2D/3D effects
- Issues of uncertainties

Uncertainties in site effects estimation methods

Numerical methods

- ! May be completely wrong if not calibrated on instrumental data
  - Uncertainty in the adopted model !
- Uncertainties depend on
  - uncertainties in input data (often large)
  - variabilities in model implementation / use
  - ⇒ New Parkfield Turkey Flat blind test

Instrumental methods

- Earthquake recordings
  - ! standard deviation around 2 on Fourier spectra
  - ? Additional variability for response spectra
- ? From Weak Motion to Strong Motion
  - no statistically significant data
  - ? modifications in the mean
  - ? modifications in the variability

Uncertainties and site effects

Epistemic / Aleatory issue

- ? reduction in GMPE σ if good knowledge of site conditions
  - Lesson from KNET/KIKNET studies : NO if site conditions are characterized by Vs30 !
  - Is Vs30 a good index of site conditions ?
    - my answer : NO; not enough ! (Californian bias ?)
- ? reduction of σ in PSHA if good knowledge of site effects
  - Should be - but how ???
  - more physical upper bounds
- better estimate of PSHA spectral shapes if good knowledge of site effects
  - Yes, definitely !