Introduction to site effects

Influence of the local geology on the ground motion

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Presentation Outline

- ✓ Introduction and general concepts
- ✓ Empirical evidence of site effects
- ✓ Linear site response
- ✓ Nonlinear site response

Introduction and General Concepts

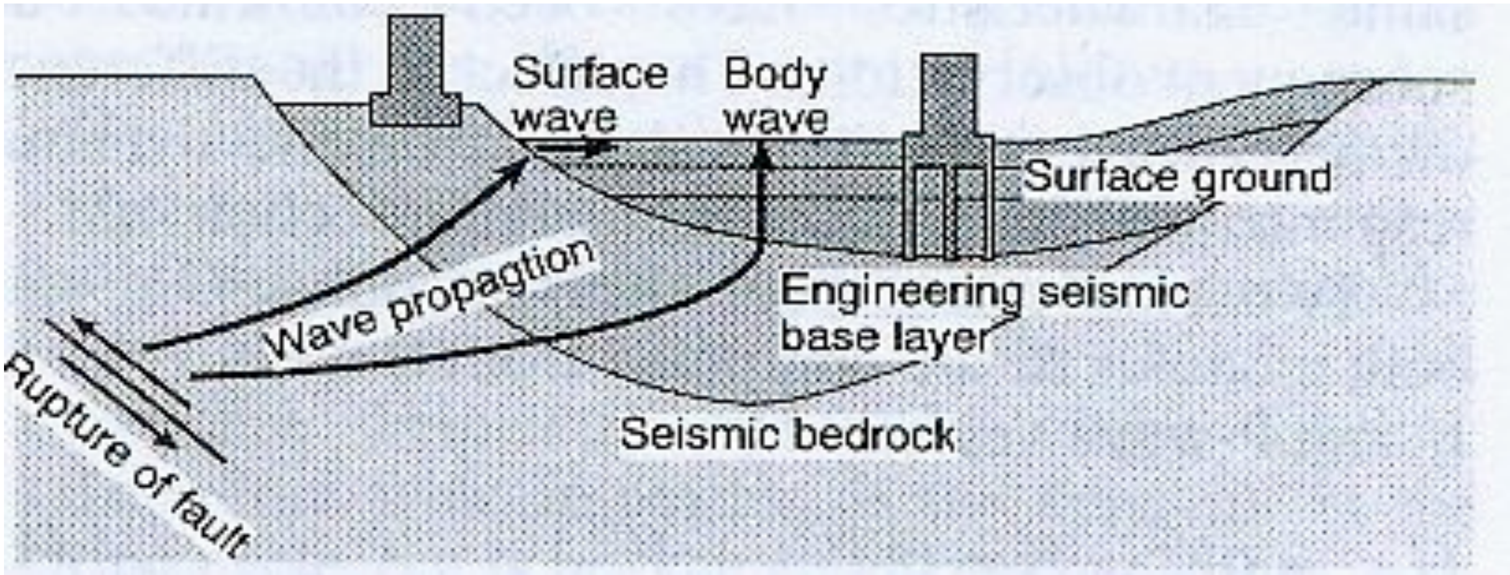
Site Response

- **Observed Records = (Source) + (Path) + (Site)**

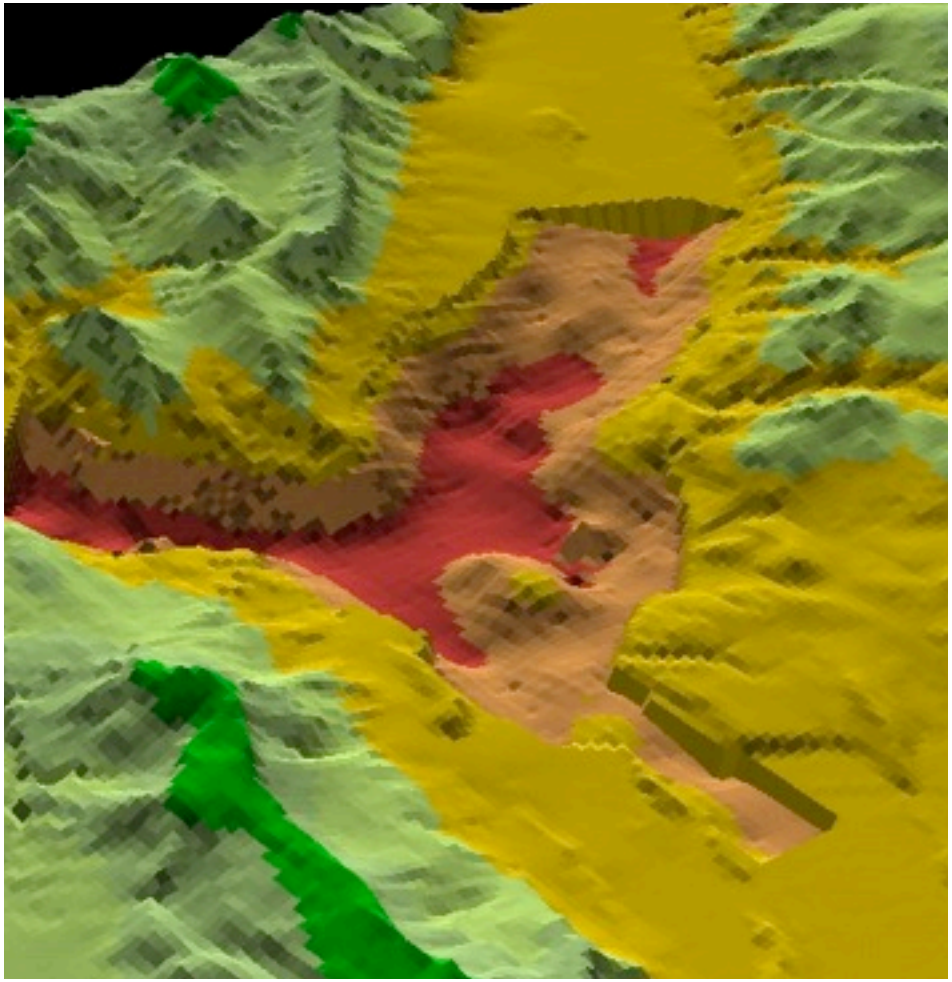
$$O_{ij}(f) = S_i(f)P_{ij}(f)G_j(f)I_j(f)$$

Assumption

- **Site response is Linear**
- **Source effects are common to each recorded data**
- **Path effects are common to all recorded data**

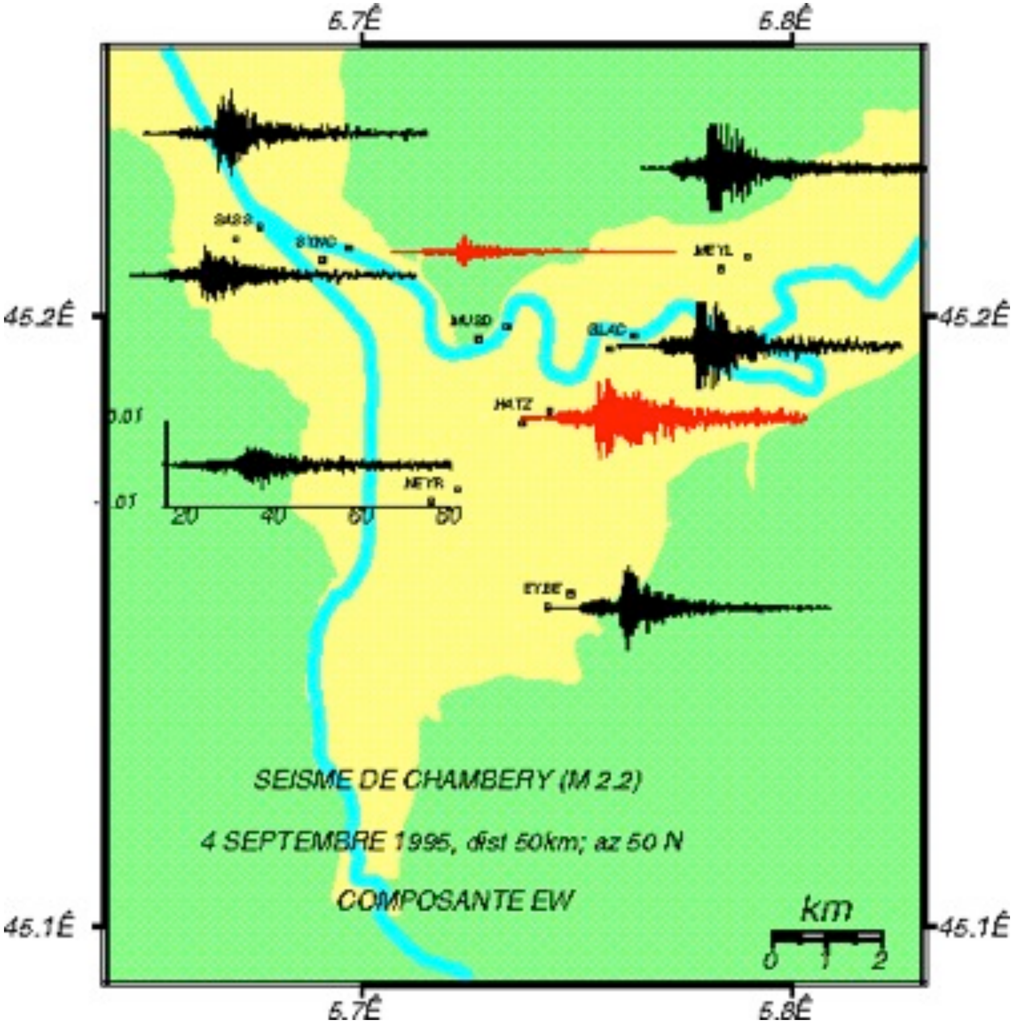


Grenoble example, France

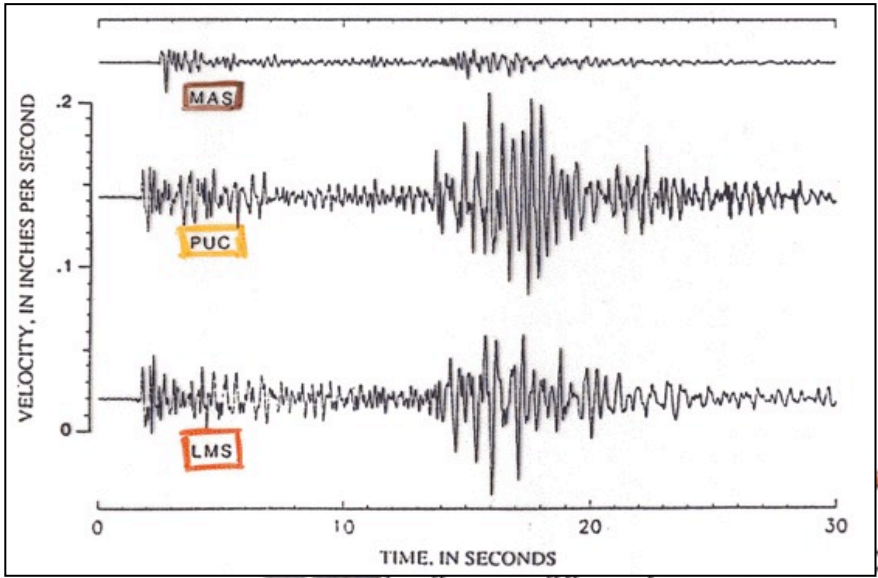


- Complex geology (3D)
- Mountain basin
- Fluvial deposits
- Glacial deposits
- Important urban development

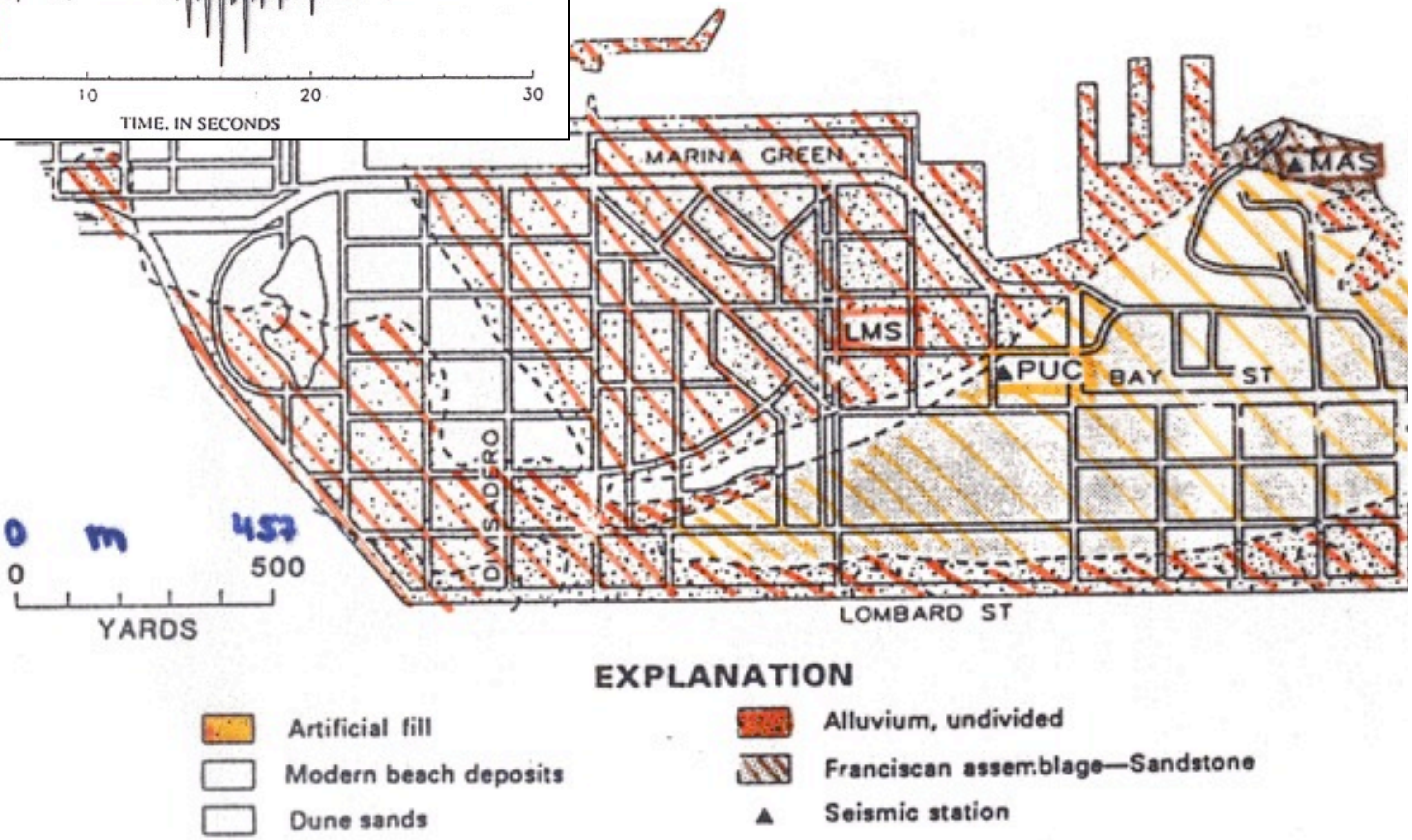
Surface observations of site effects



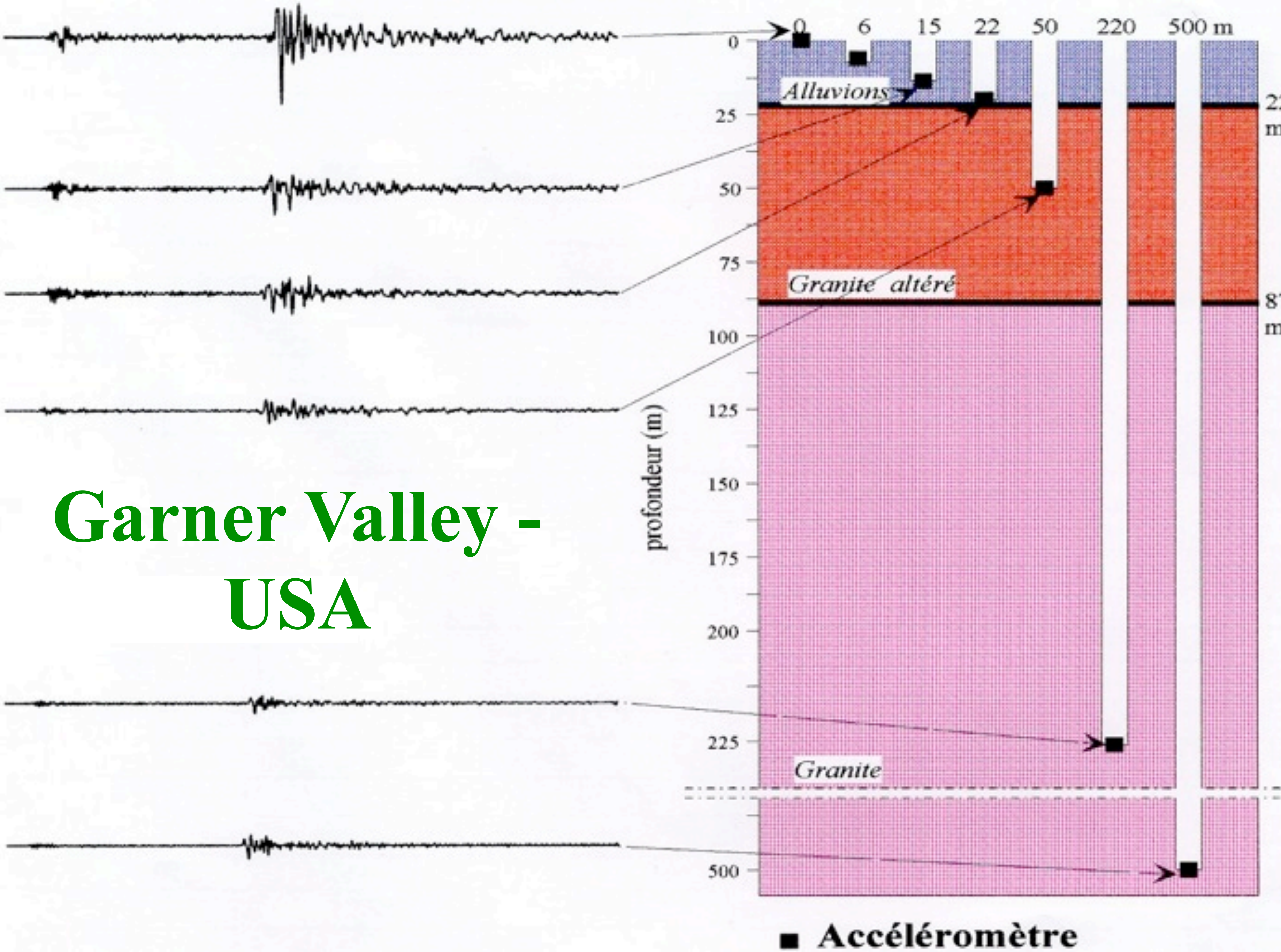
- ✓Amplification of the ground motion
- ✓Increment of the signal duration
- ✓Ground motion variability



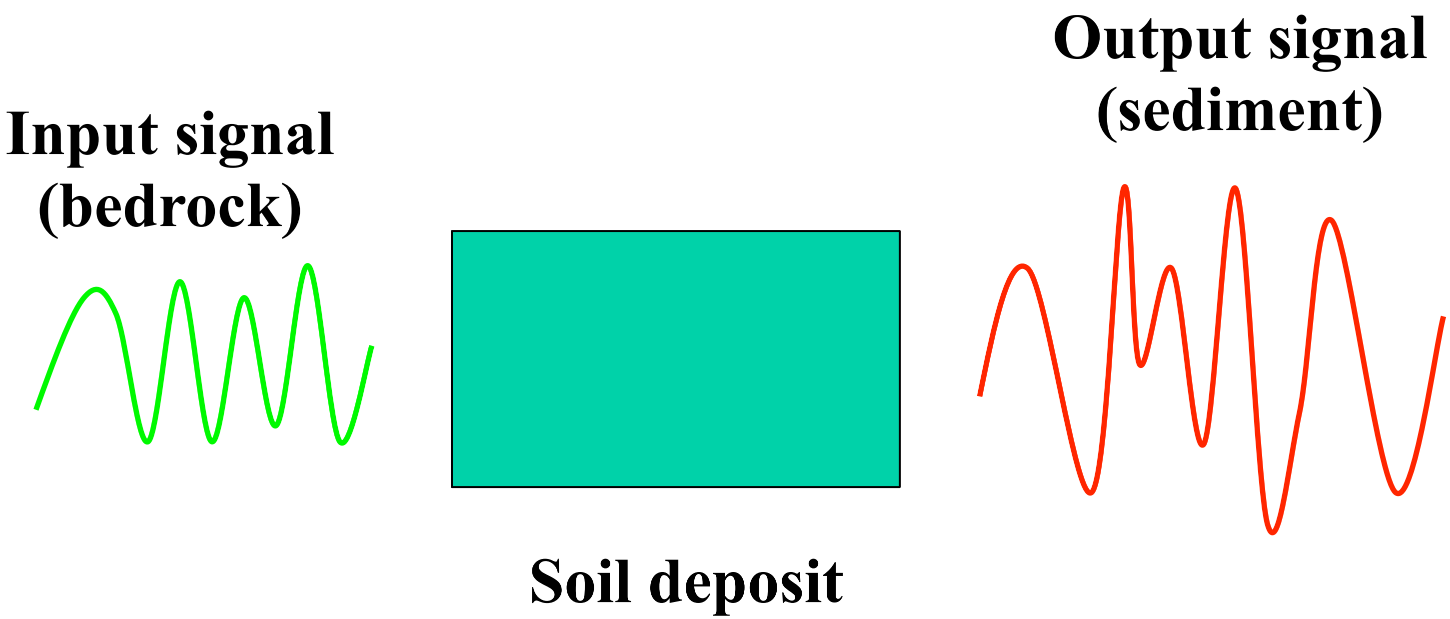
San Francisco Bay (USA)



Garner Valley - USA

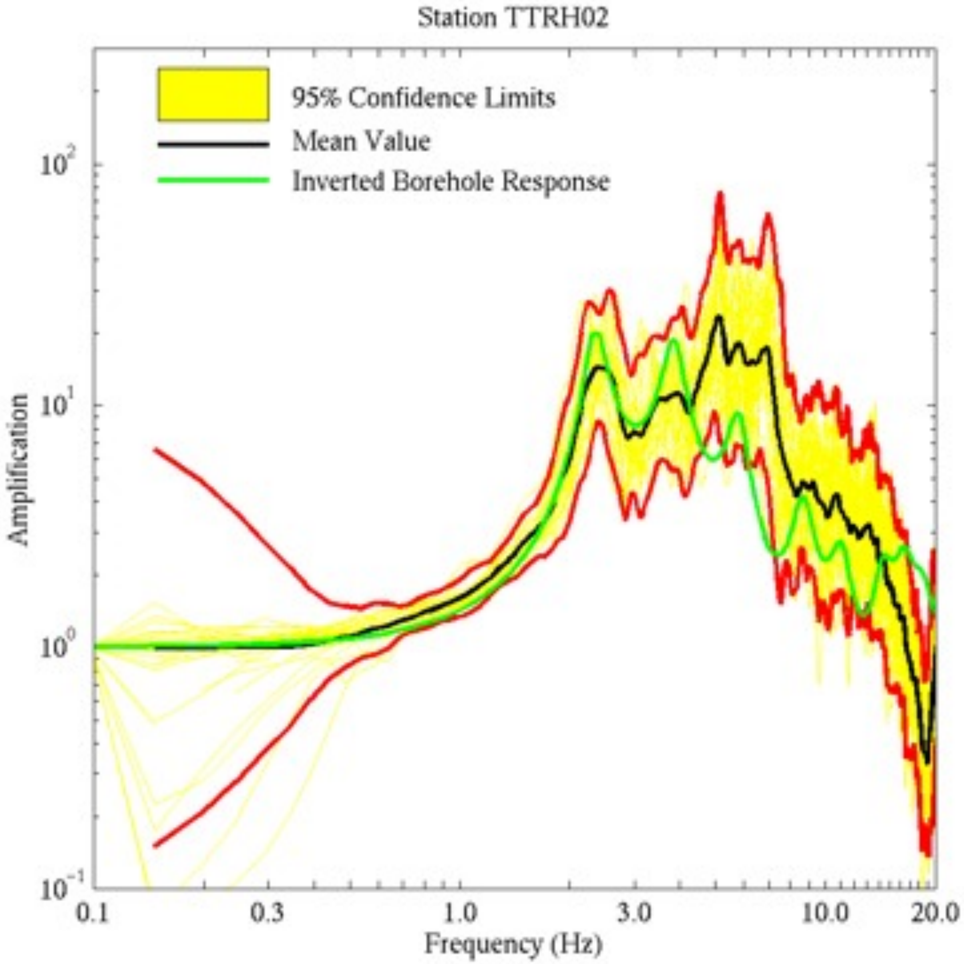


Site effect definition



Site effect = Output / Input (deconvolution)

Site response quantification



- The response is broadband
- The mean value is stable

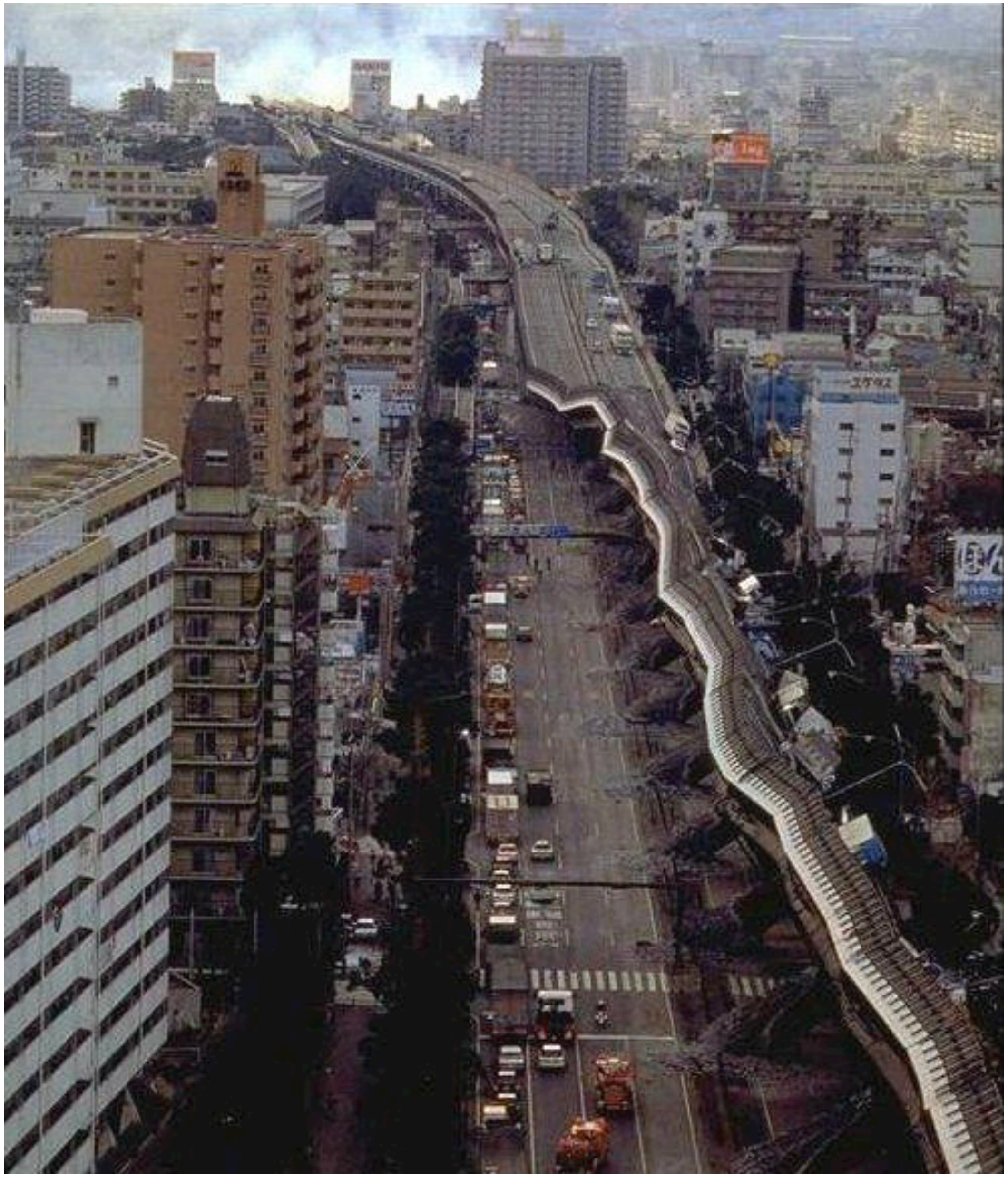
Site effects

- **Definition:** **Influence of local geology on the seismic wave propagation. Site response is measured using the so-called transfer function**
- **Linear site effects:** **the transfer function is independent of the input**
- **Nonlinear site effects:** **strong feedback between the input and the medium**

Engineers design earthquake resistant structures including site effects (if present)

Empirical Evidence of Site Effects

Northridge M6.7, 1994 (USA)



Kobe M6.9, 1995 Japan

- Near source effects
- Site effects
- Bad design

Theoretical Computation of Site Response

Site effects - physical basis

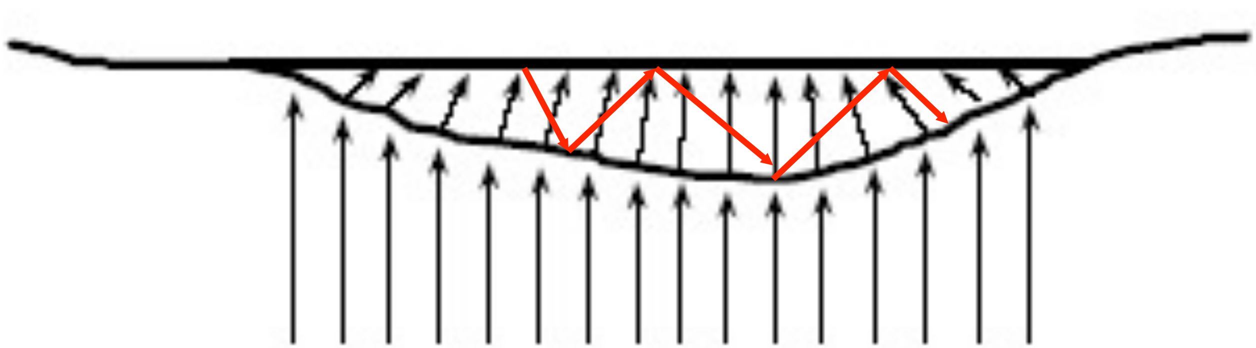
Effect of the local geology on the ground motion

- Refraction, diffraction, focalization
- Trapped waves
  - vertical reverberations
  - horizontal reverberations

! + nonlinear soil behavior !

Consequences

- Constructive interference: amplification
- Trapped waves: increase of the seismic duration
- Resonance of fundamental and harmonic modes

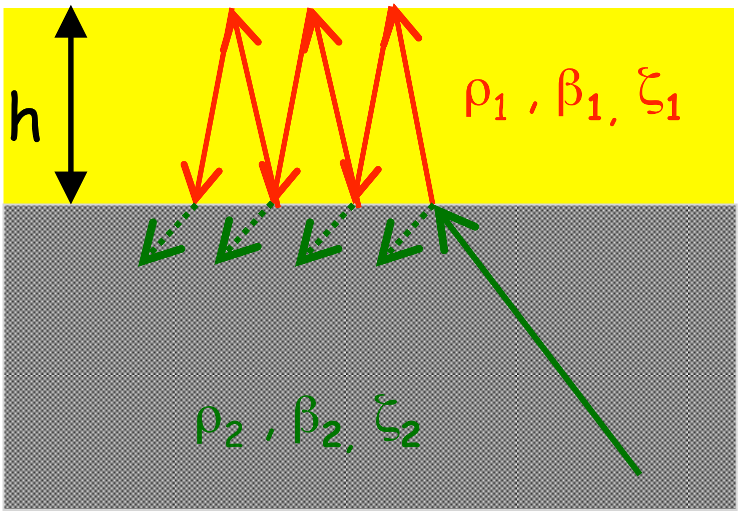


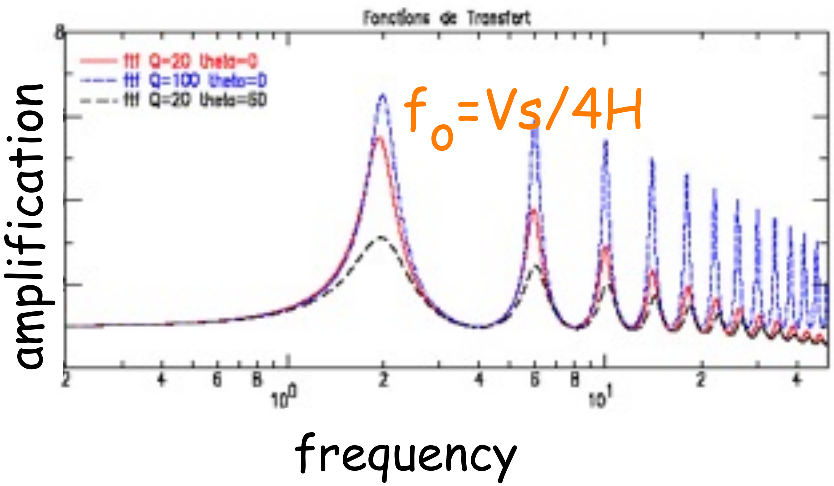
Bard (2006)

Where does the amplification come from?

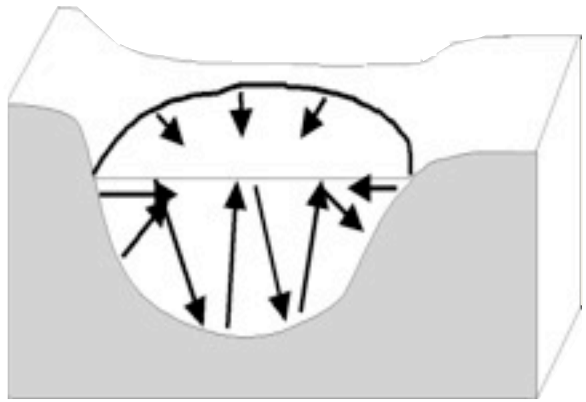
Bard (2006)

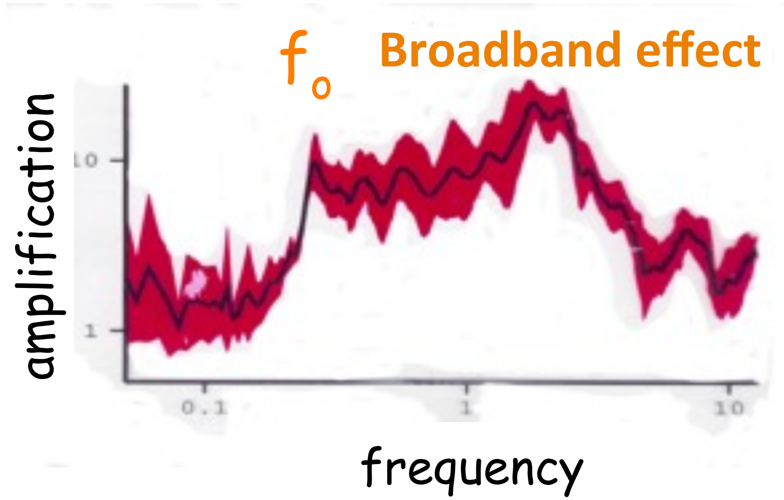
1) 1D case:
vertical reverberations



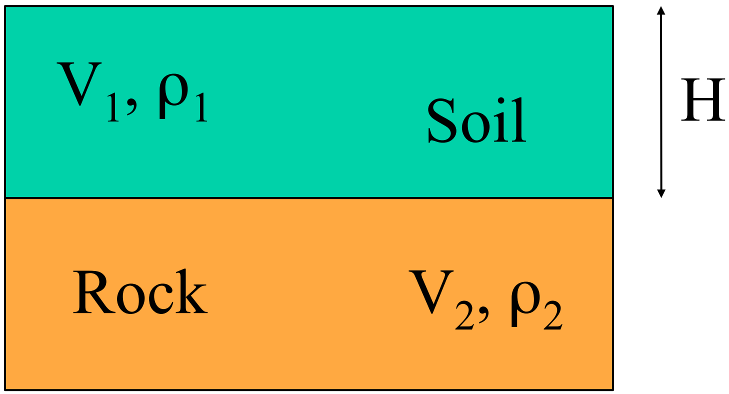


2) 2D / 3D case:
Lateral reverberations





Simplified Computation (1D)



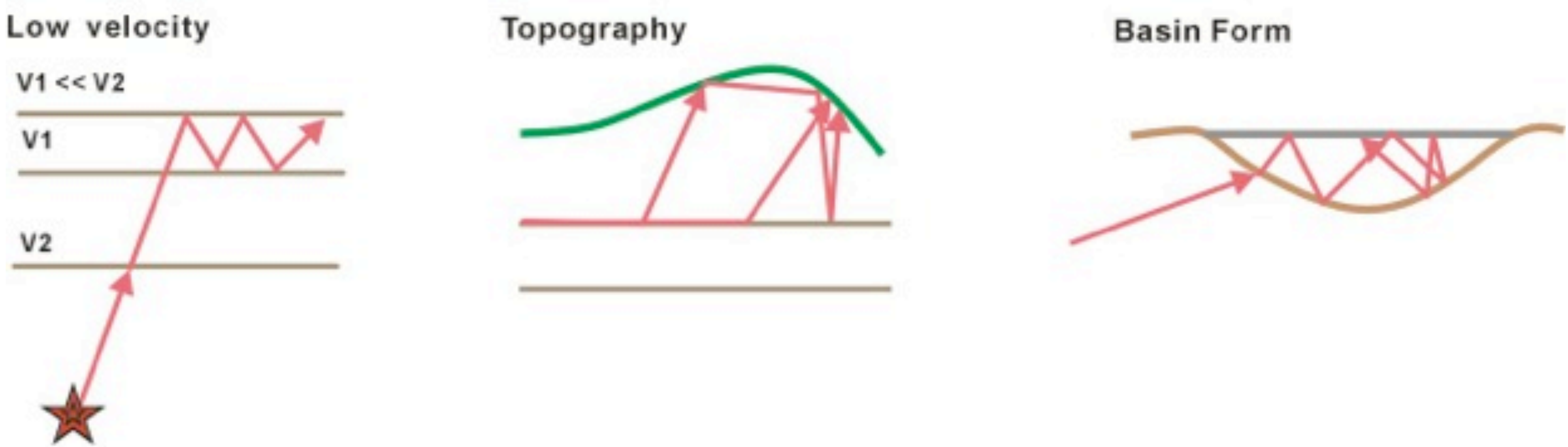
Amplification

$$A = \frac{1}{\sqrt{\cos^2(2\pi f H / V_1) + [\xi(2\pi f H / V_1)]^2}}$$

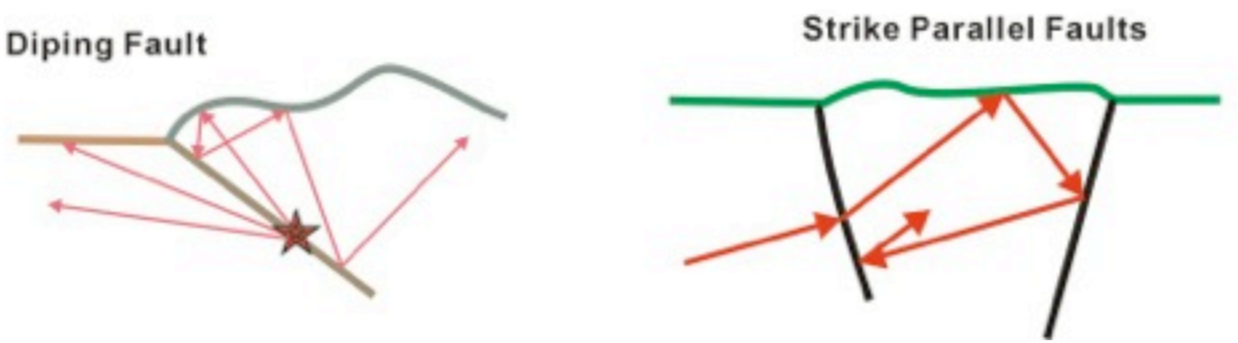
Resonance Frecuency

$$f_0 = \frac{V_1}{4H}$$

Why do we have site effects?

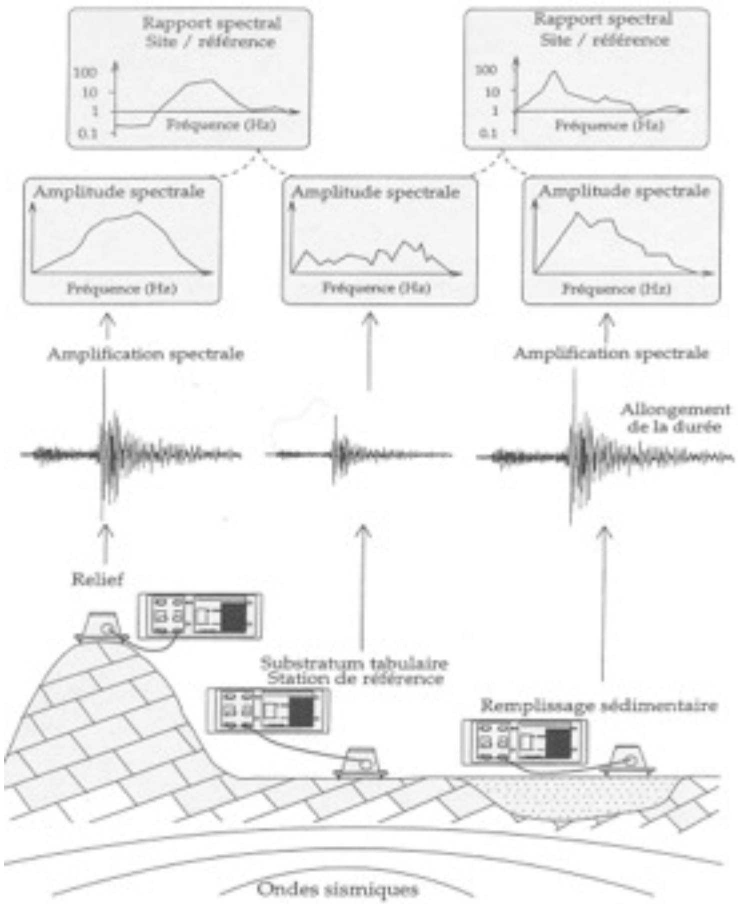


New Effects (Taiwan)

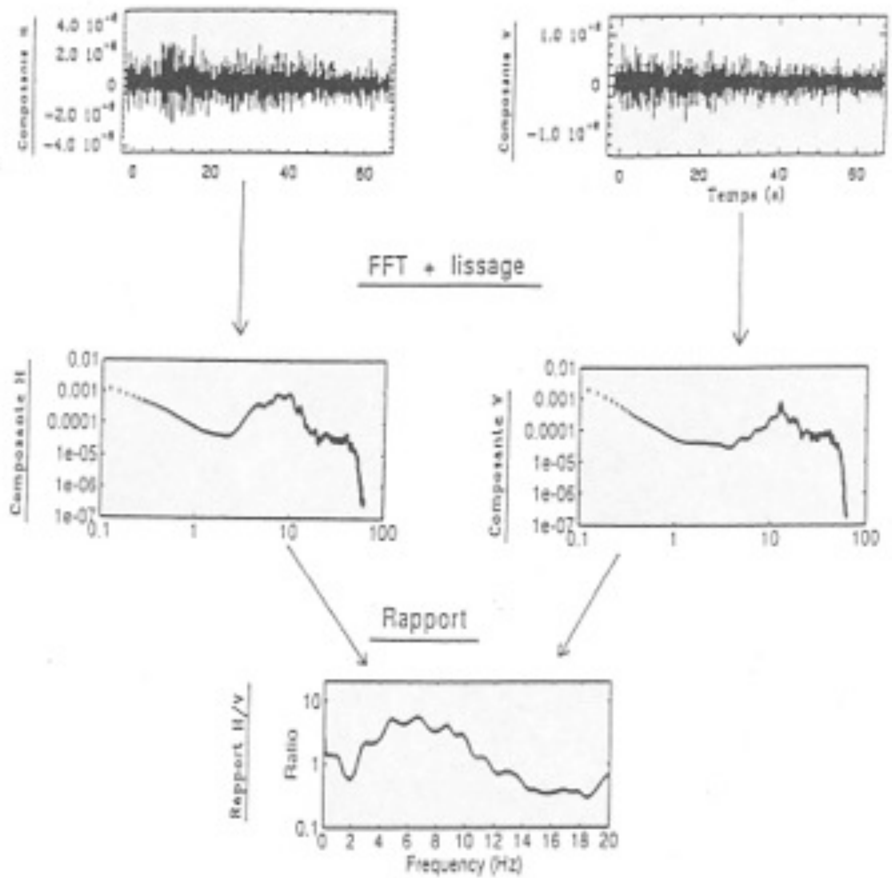


Empirical estimation of site effects

Spectral ratios (earthquakes)

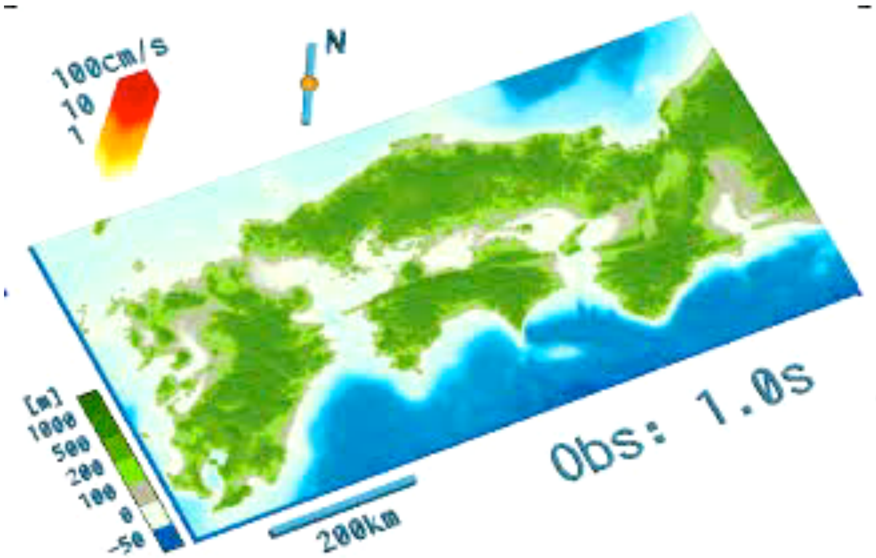


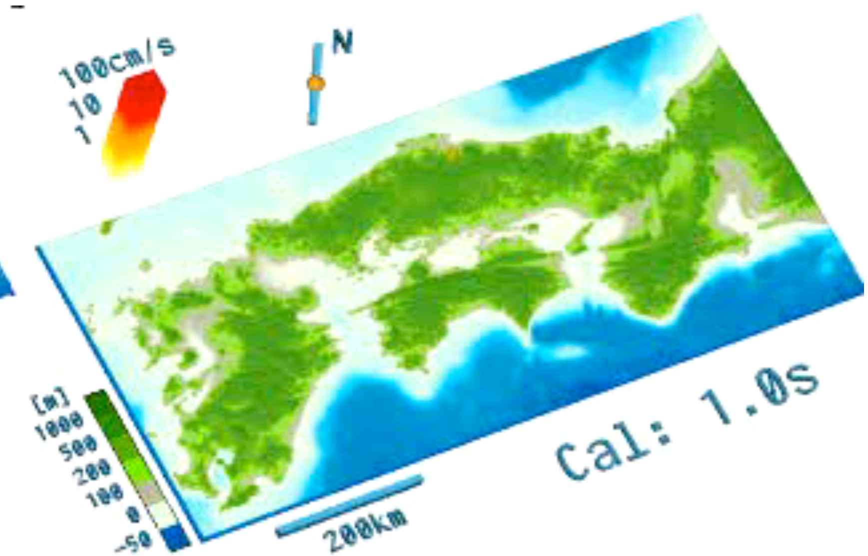
H/V (noise)

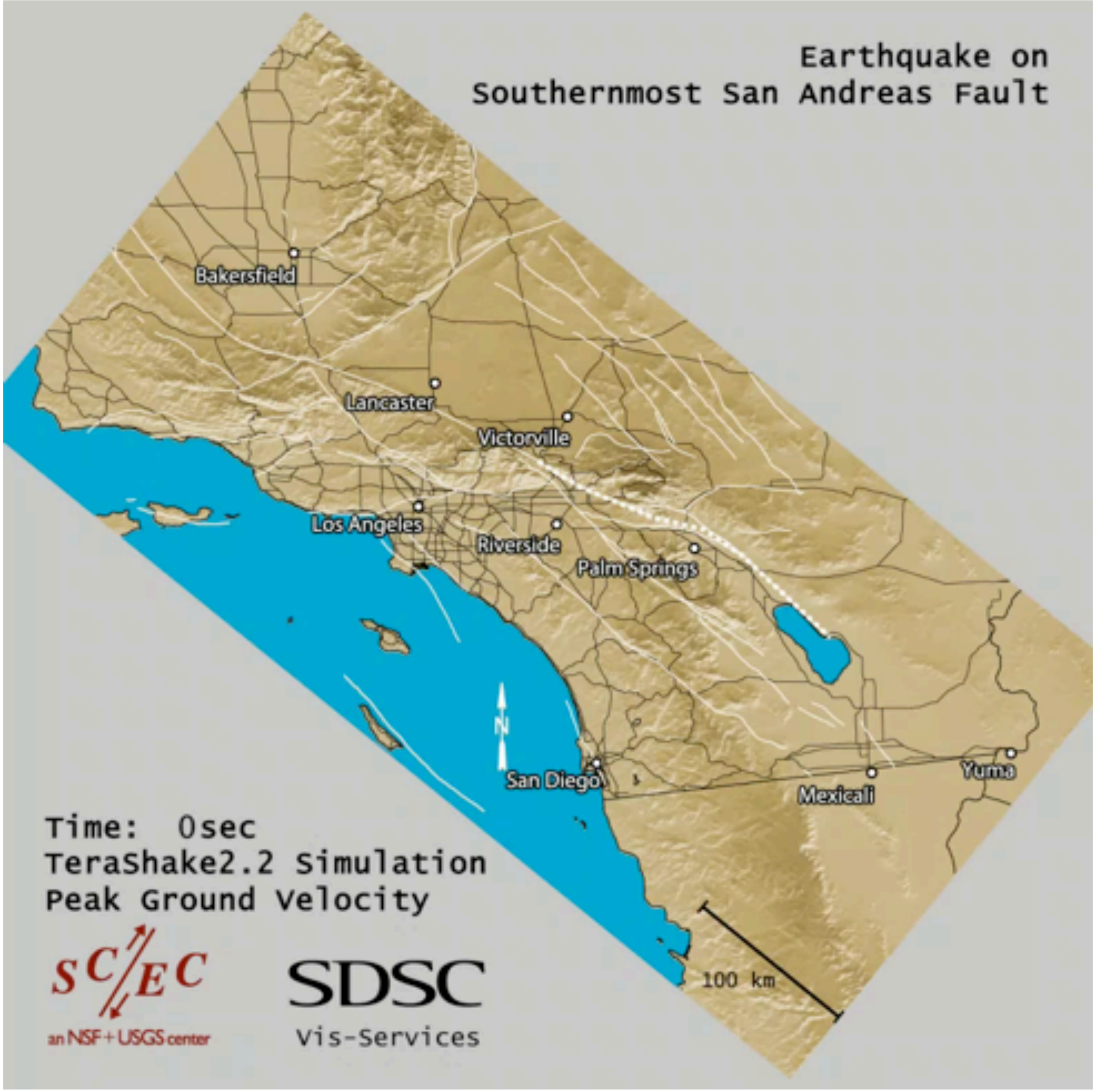


Resonance frequencies and related soil amplification

Site effects in complex media (movies)


100cm/s
10
1
N
[m]
1000
500
200
100
0
-50
200km
Obs: 1.0s

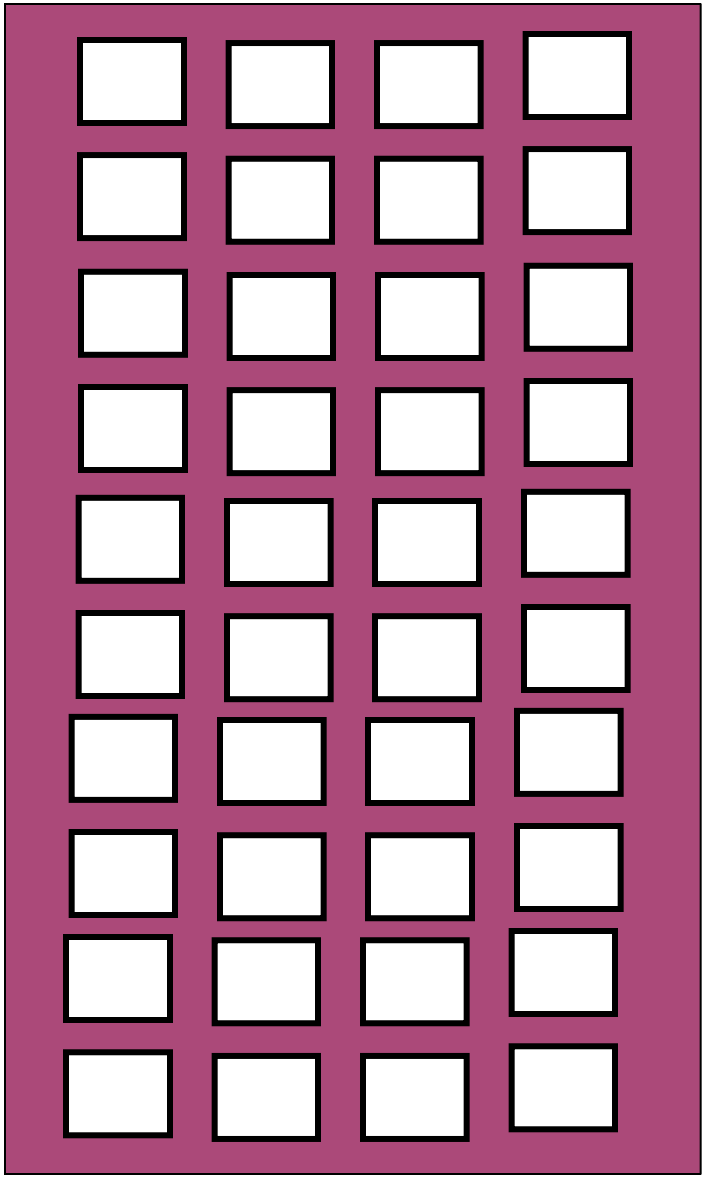

100cm/s
10
1
N
[m]
1000
500
200
100
0
-50
200km
Cal: 1.0s



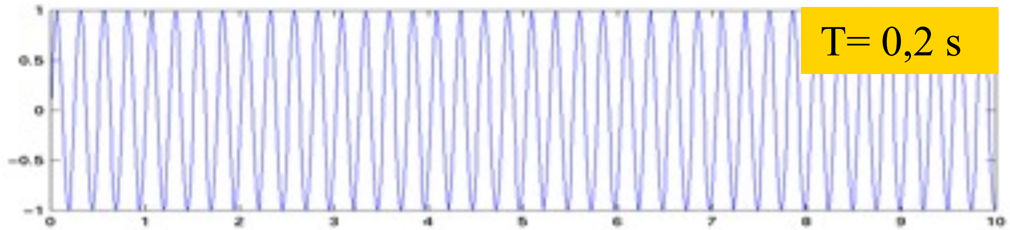
Earthquake on
Southernmost San Andreas Fault
Bakersfield
Lancaster
Victorville
Los Angeles
Riverside
Palm Springs
San Diego
Mexicali
Yuma
N
100 km
Time: 0sec
TeraShake2.2 Simulation
Peak Ground Velocity
SCEC
an NSF+USGS center
SDSC
Vis-Services

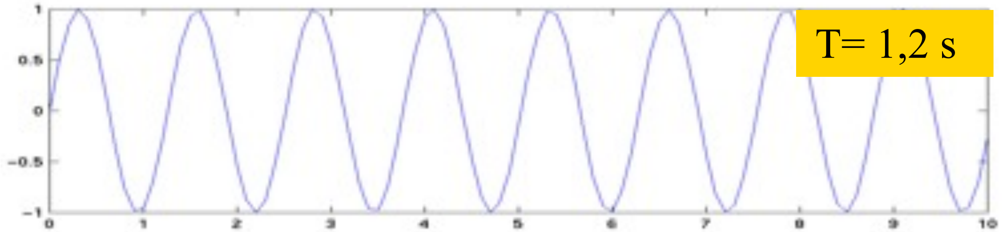
Site Effects and Urban Planning

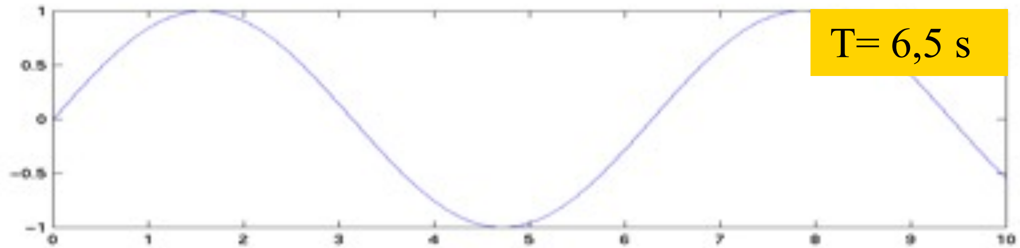
A structure has a fundamental period of vibration



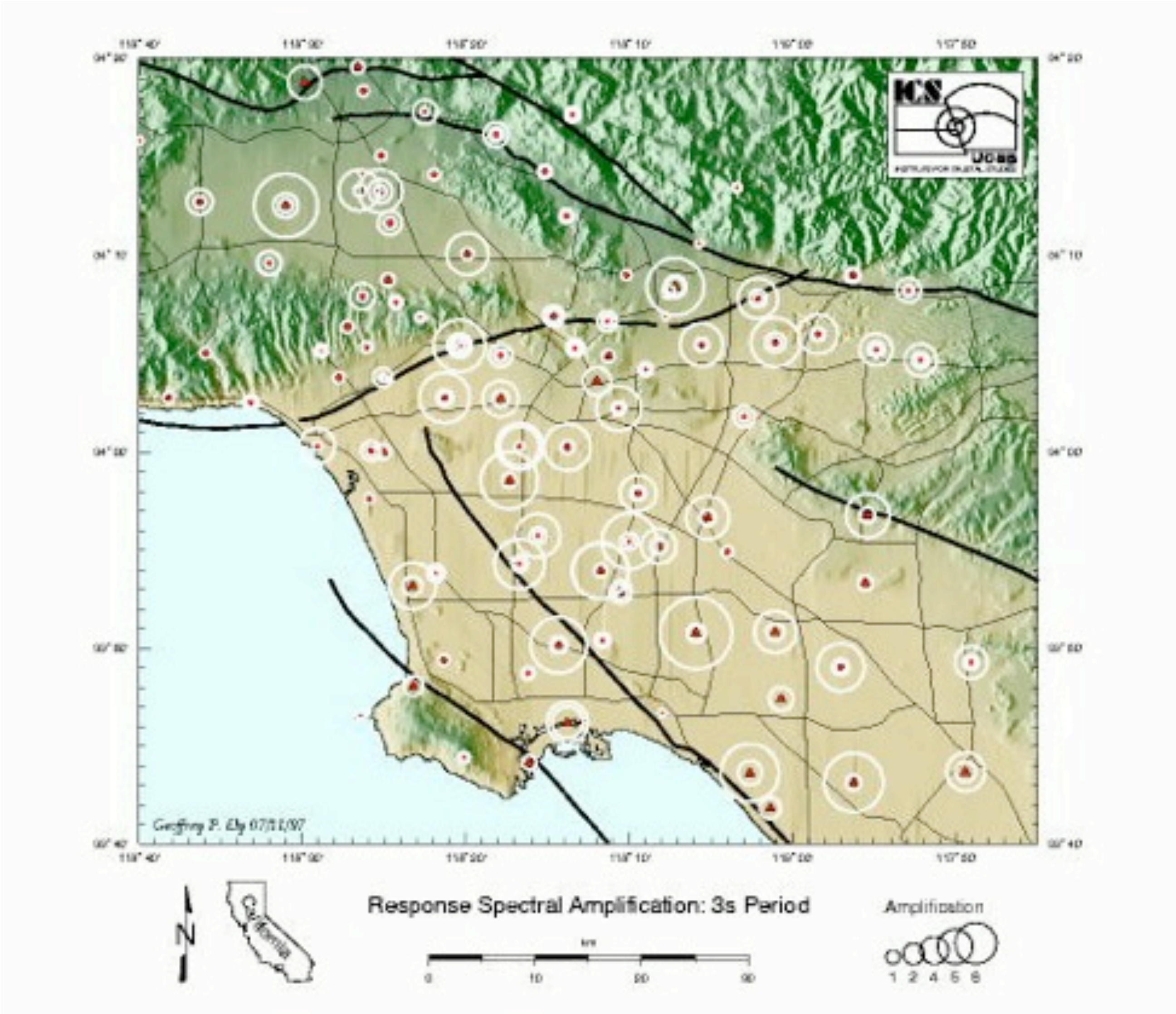
10 stories $$T_0 \approx \frac{N}{10} = 1s$$







Amplification: Los Angeles at T=3s



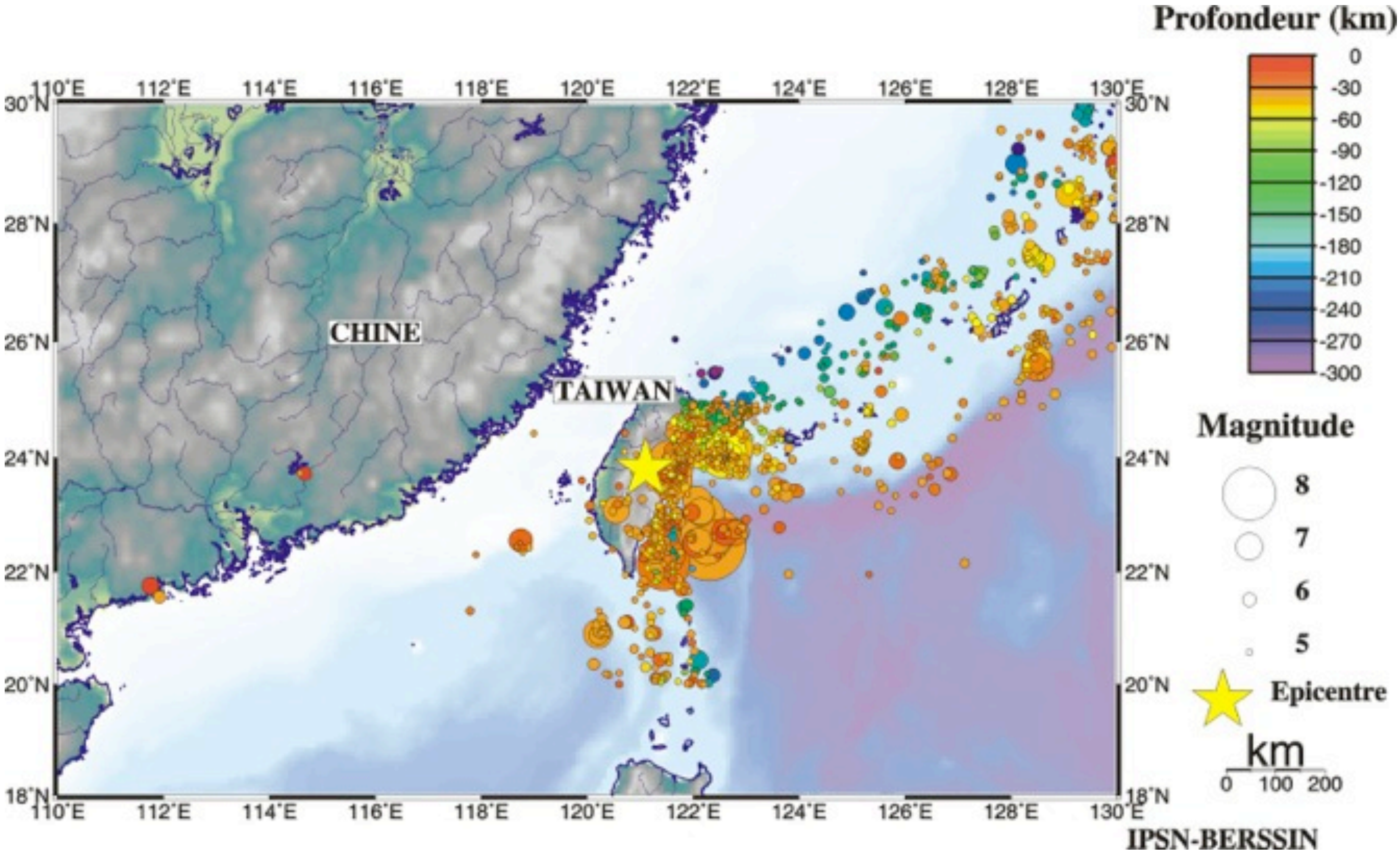
Soil Classification

Ground Type	Parameter Vs30 (m.s^-2) **[EC8]**
A	>800
B	360 – 800
C	180 – 360
D	<180
E	C or D layer, underlain by stiffer material with Vs>800 m.s^-2

Vs : average shear wave velocity in the first 30 meters

Site Response and Ground Motion Attenuation

Chi-Chi M7.2, 1999 (Taiwan)



PGA – Distance Distribution

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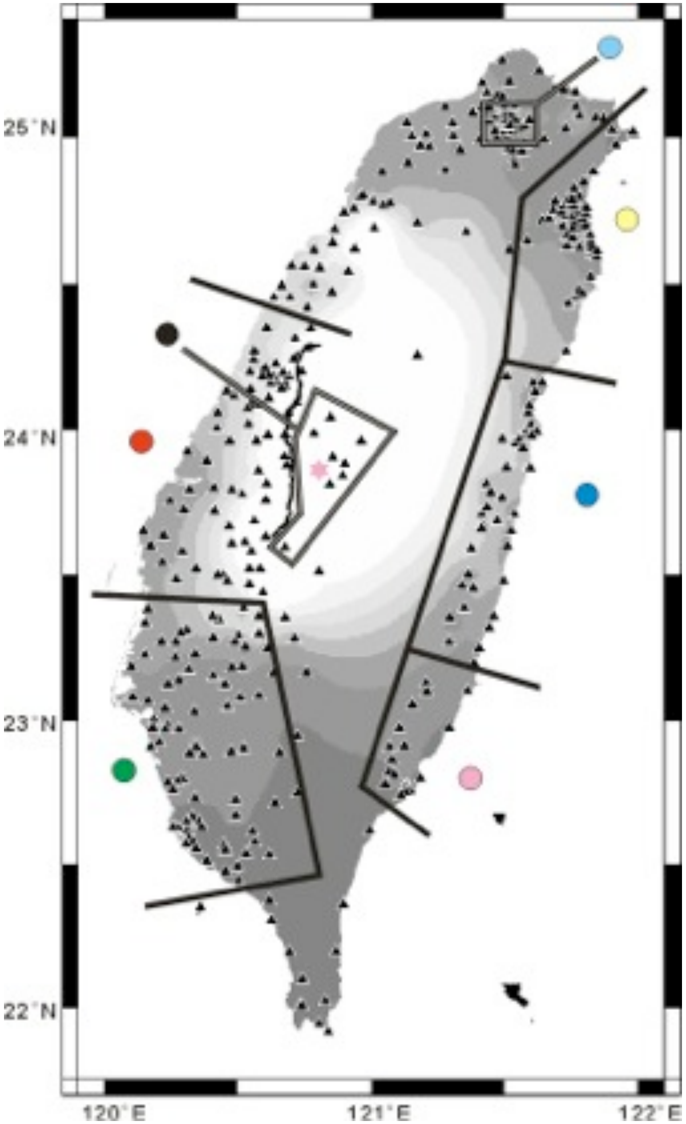
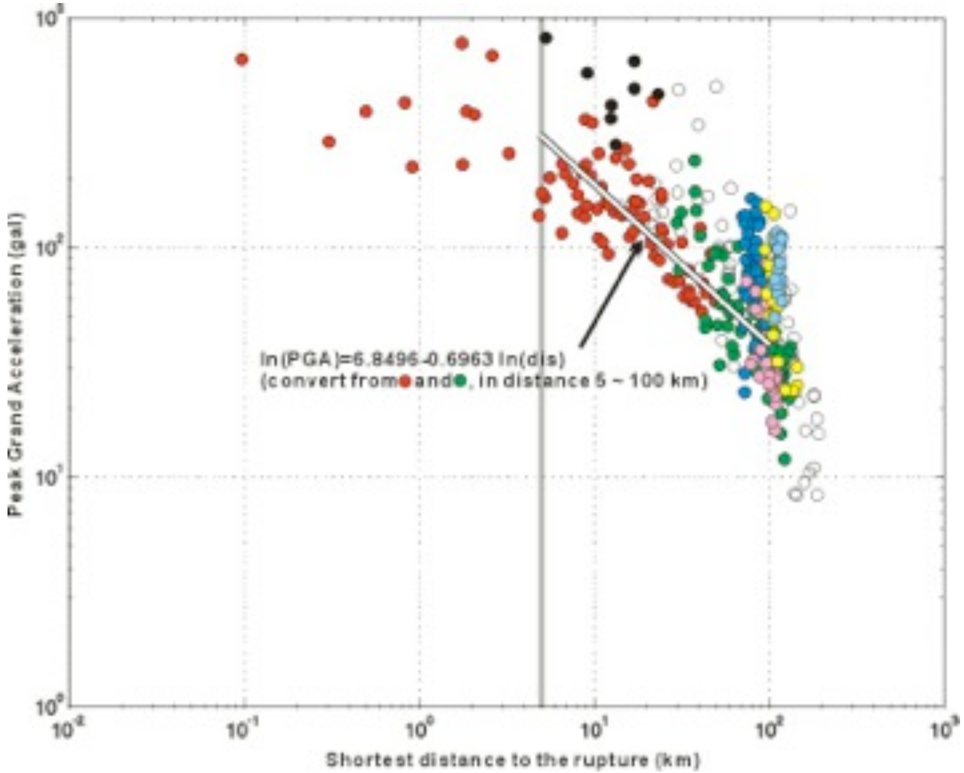




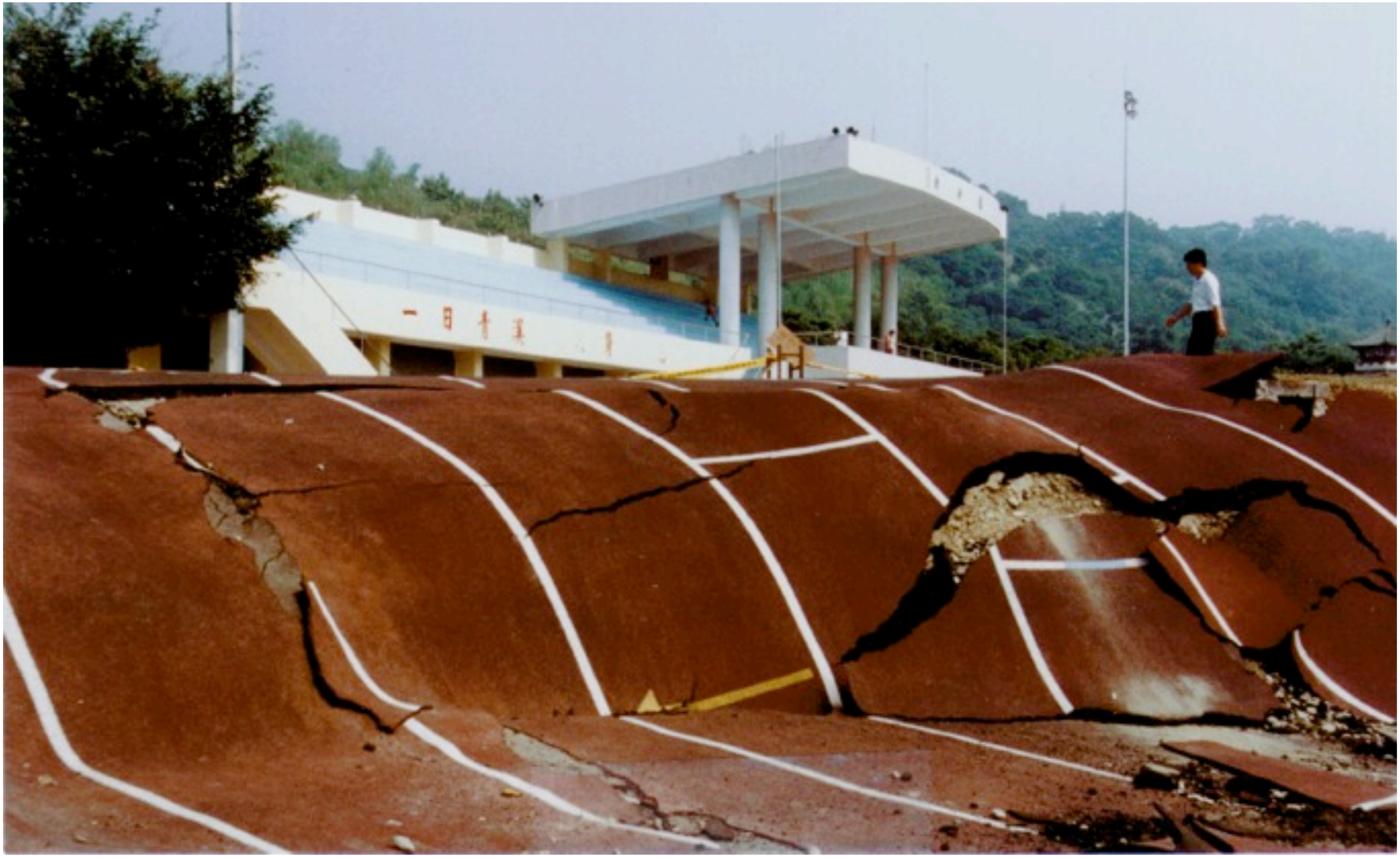
Nonlinear Site Effects

Chi-Chi M7.2, 1999 (Taiwan)

Chi-Chi M7.2, 1999 (Taiwan)

Vertical displacement (~10 m) of the dam

Chi-Chi M7.2, 1999 (Taiwan)



Tottori, Japan 2001

Examples of landslides

Chi-Chi, Taiwan, 2000

Liquefaction examples (free field)

Liquefaction of the soil foundation

Soil liquefaction of the bridge's soil foundation

Kobe: Jan. 1995, M6.9

Vertical Settlement

Photo 5. Sand boils and seismometer at the Port Island Borehole Array Station installed by Kobe Development Bureau

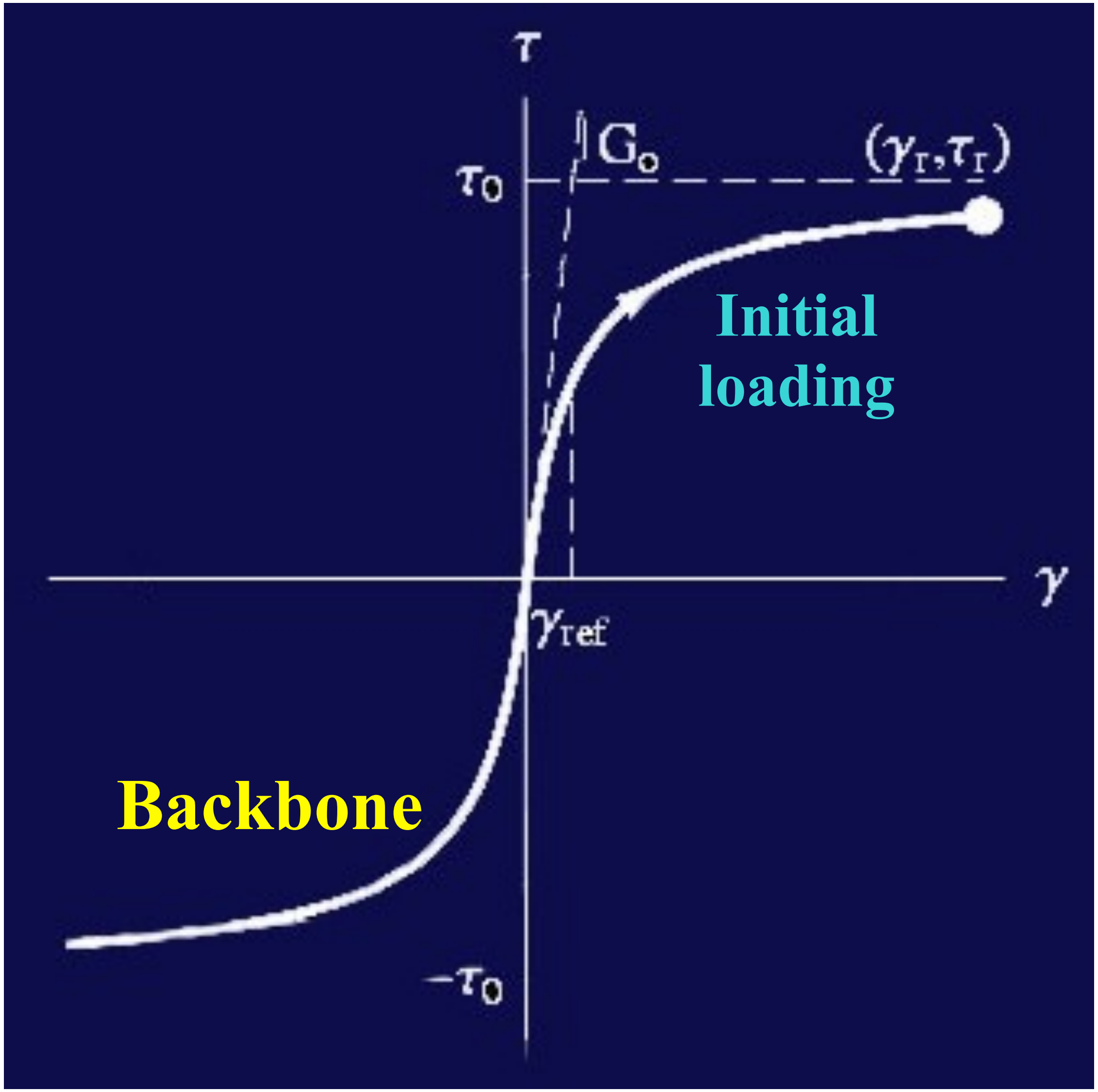
The borehole array station installed in northwest of Port Island recorded ground motion at four depths (0 m, −16 m, −32 m, −83 m). Extensive sand boils were observed at the same site. (by F. Oka, Gifu University).

Photo 11. Damaged caisson type quay walls at Port Island in Kobe Port

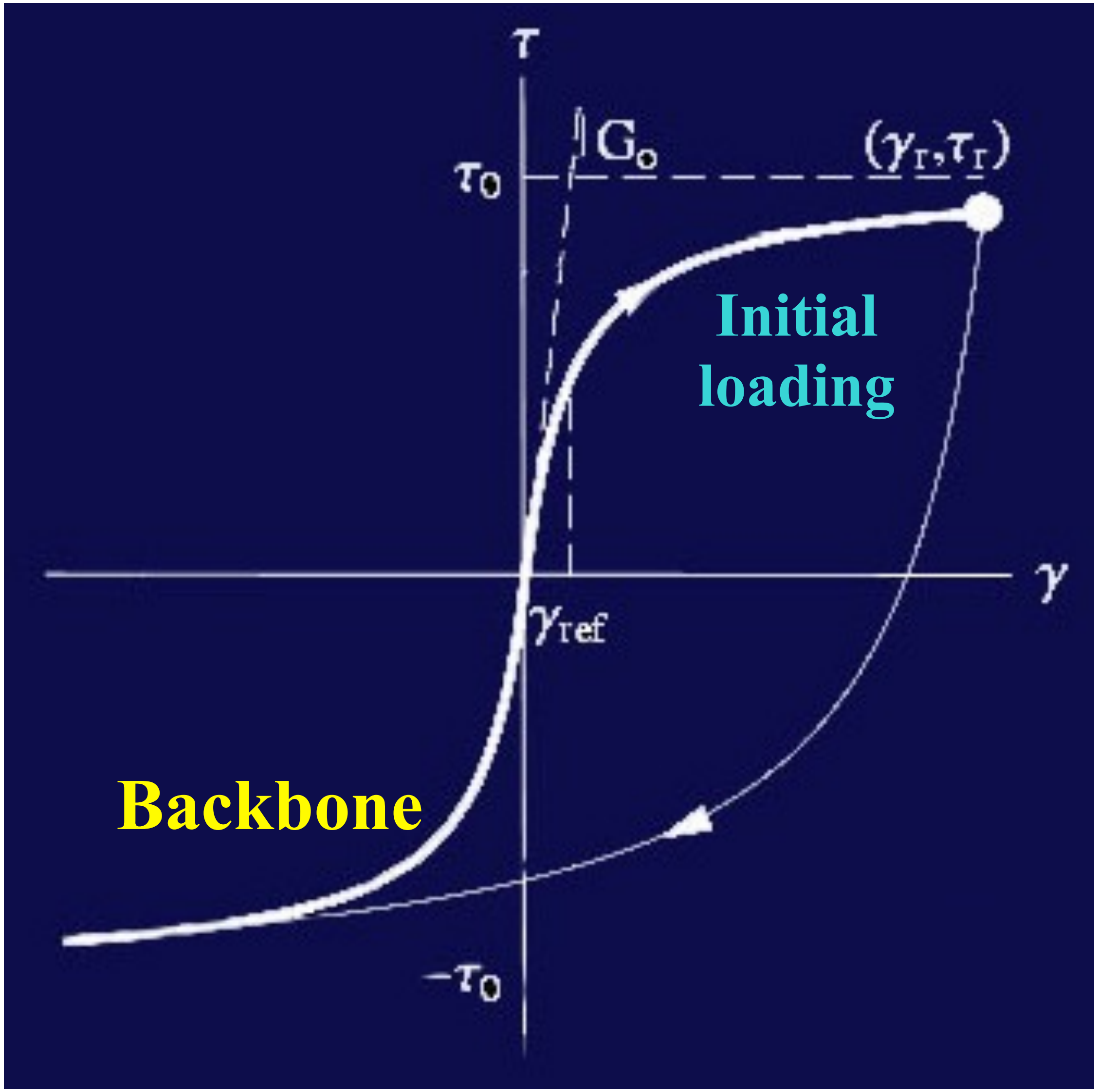
Many caisson type quay walls were damaged in Kobe Port. Seaward displacements of the caisson walls were about 5 m at maximum and 3 m on an average. The soils behind the wall settled accordingly. (by S. Iai, Ministry of Transport)

Lateral Spreading

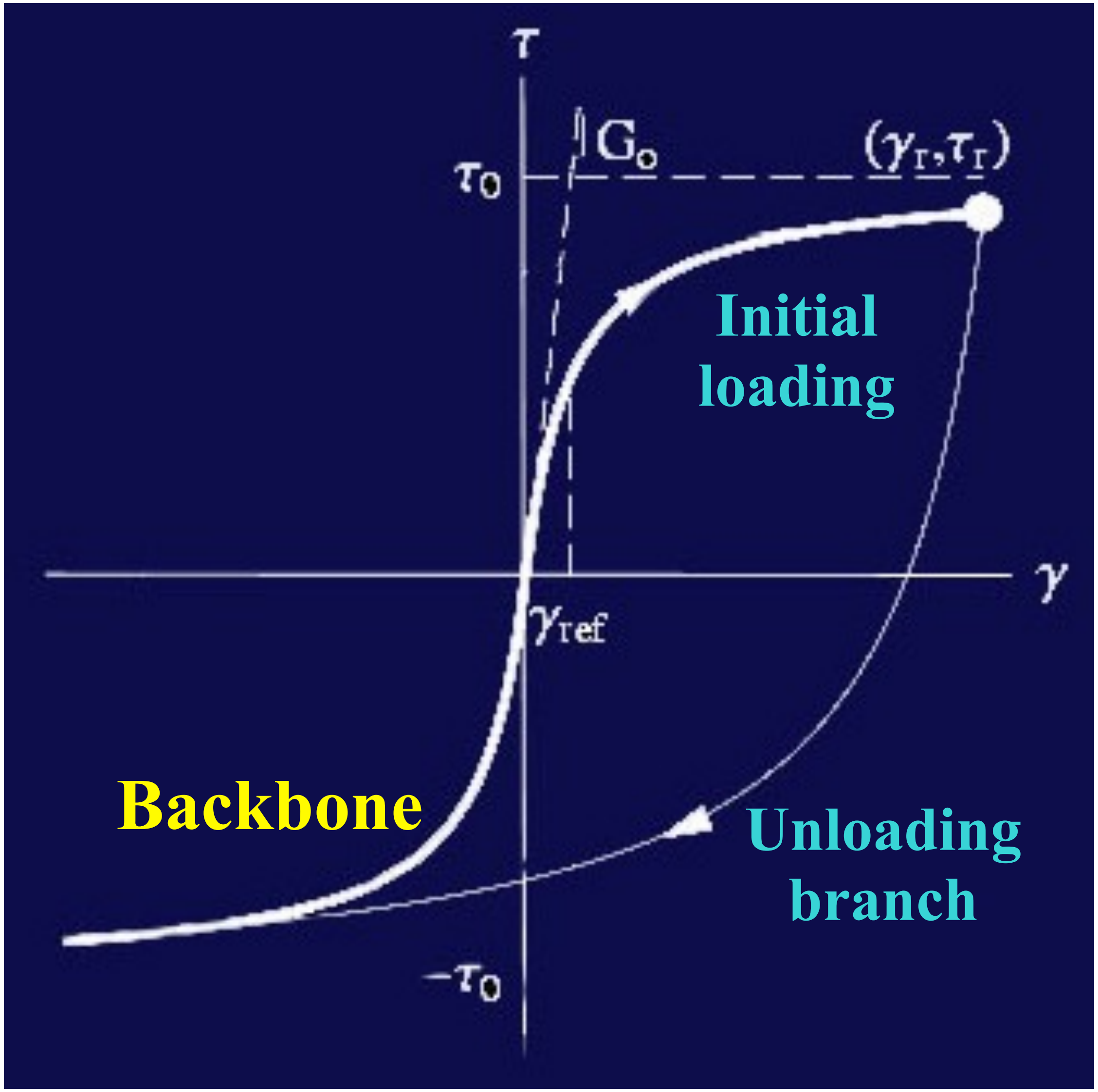
Hysteresis model



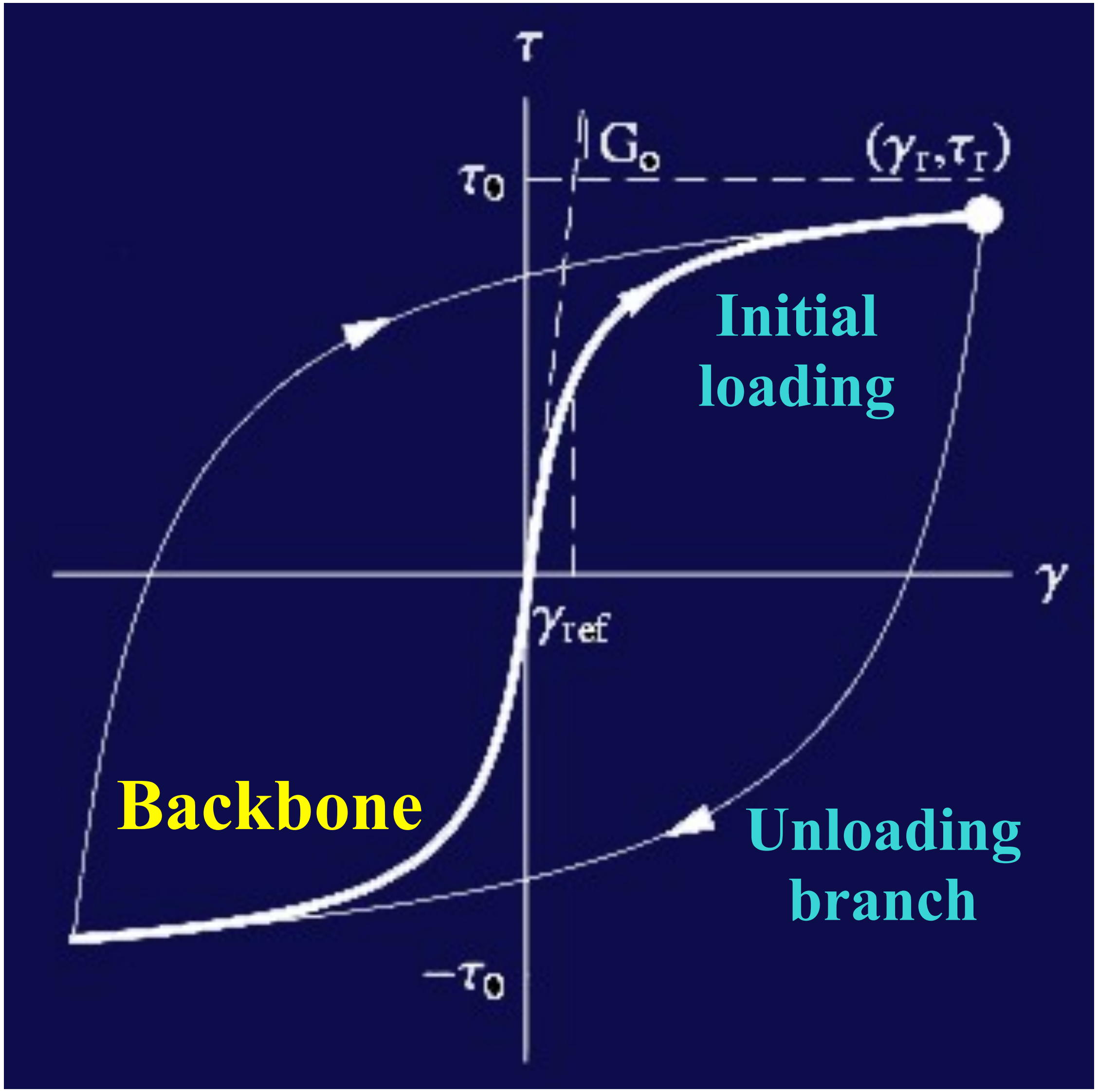
Hysteresis model



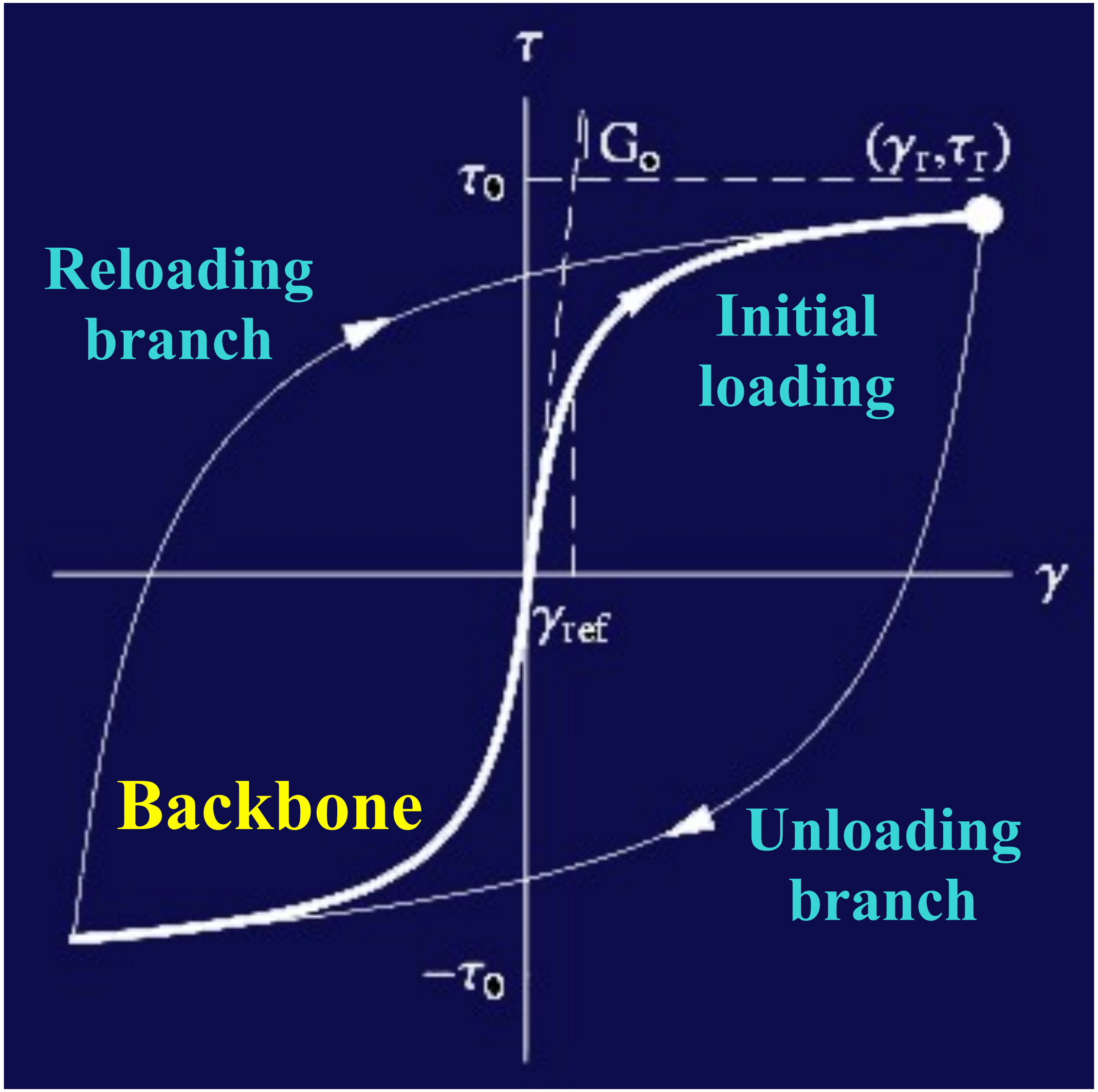
Hysteresis model



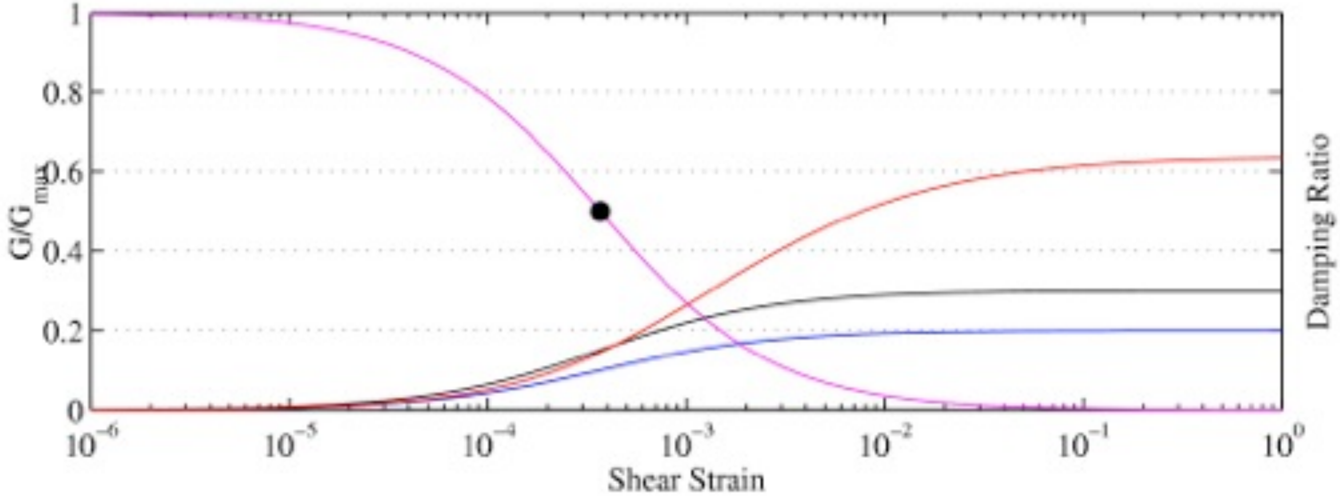
Hysteresis model



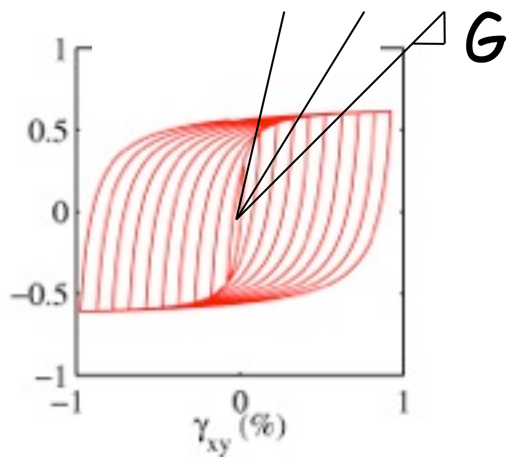
Hysteresis model



Modulus degradation and damping curves



- The shear modulus decreases for increasing deformation levels
- The damping increases proportionally to the deformation



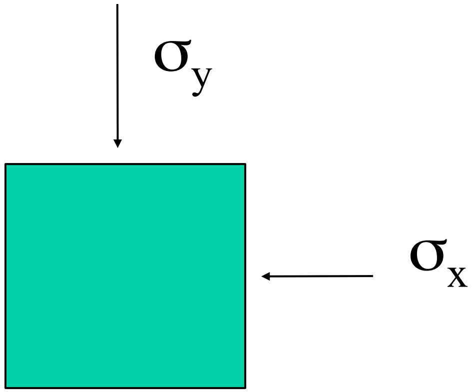
How is the transfer function affected?

1. The shear modulus is computed as $G=\rho\beta^2$
2. The fundamental frequency of the soil is $f_0=\beta/(4H)$
3. If G changes, so does β :
   if $G(-) \dashrightarrow \beta(-) \dashrightarrow f_0(-)$

✓Deamplification: the damping increases (pay attention)

✓Increase of the signal duration (long period waves arrive later)

The effect of depth



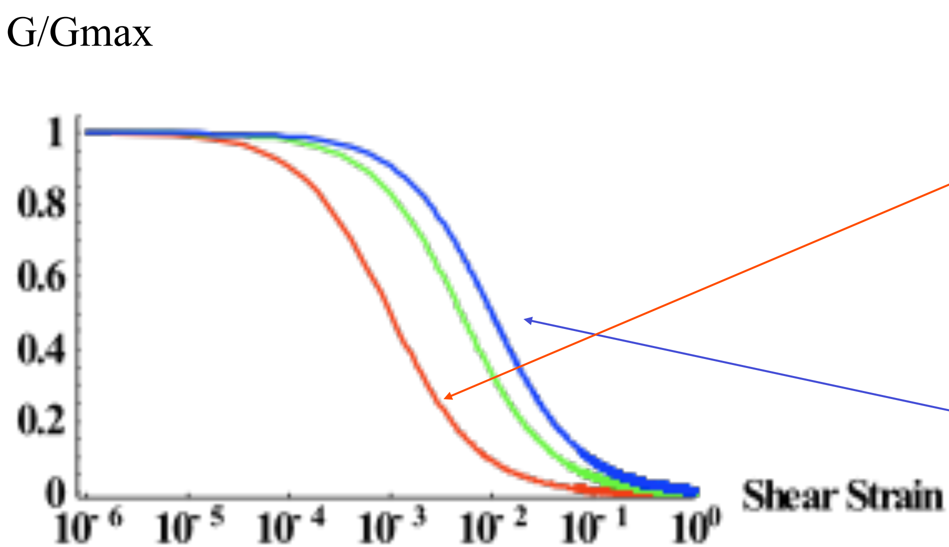
Initial conditions

$$\sigma_{y0} = \rho\ H\ g$$

$$\sigma_{x0} = K_0\ \sigma_y$$

$$\sigma_{m0} = (2\sigma_{x0}+\sigma_{y0})/3$$

$$\tau_{max} = \sigma_{m0}\ \sin(\phi)$$



More nonlinearity at shallow depths

More linear at depth

Numerical solution

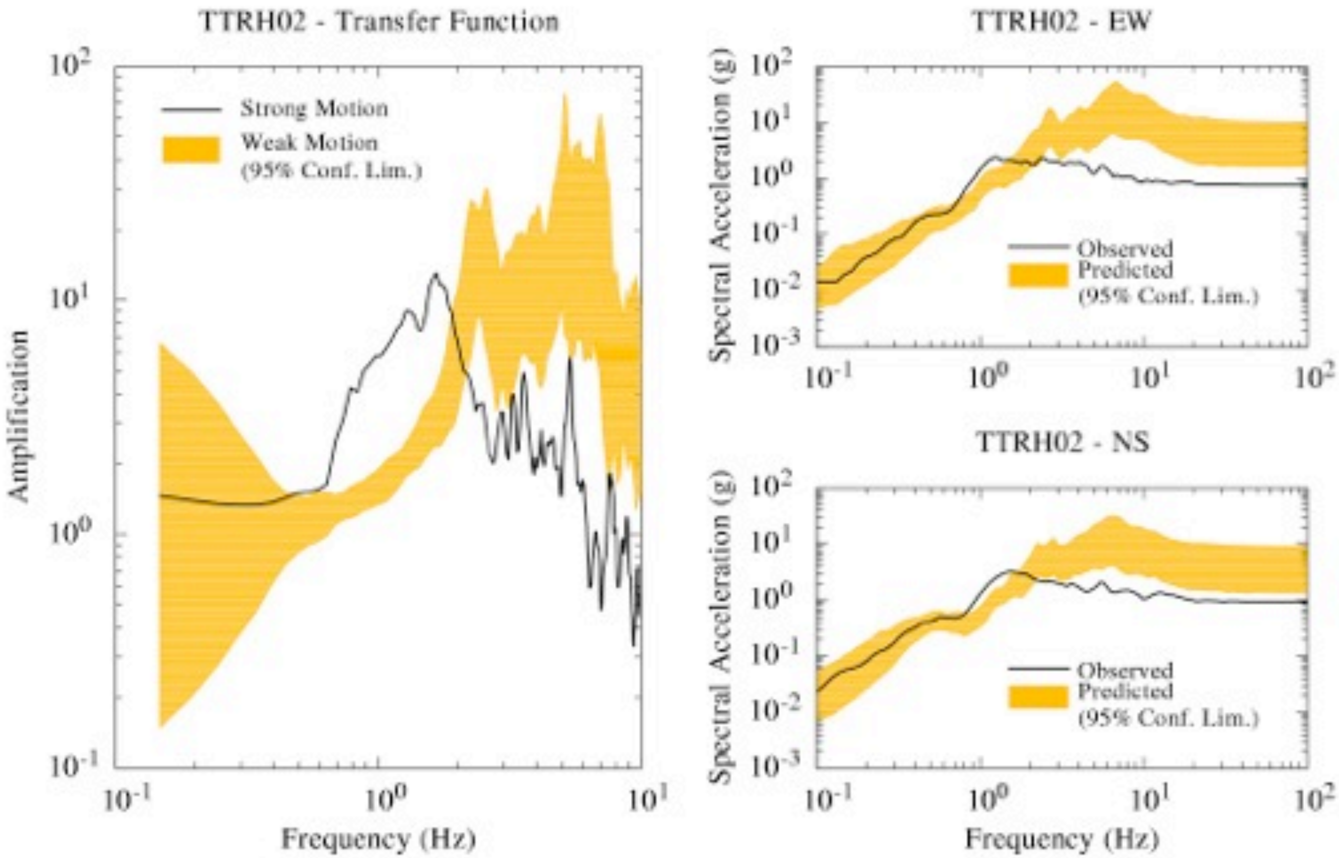
Why?

- There is no analytical solution
- Finite differences, spectral elements, finite elements methods

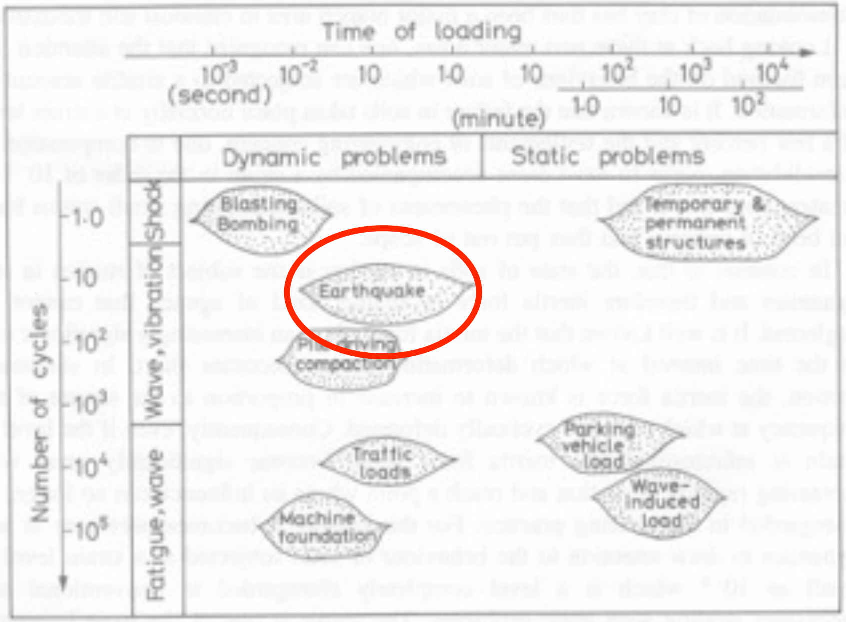
Boundary conditions:

- Surface: free surface effect
- Bedrock: elastic boundary conditions (transmitted waves) or rigid boundary conditions (complete reflection)

Nonlinear Effects: TTRH02 Station (Japan)



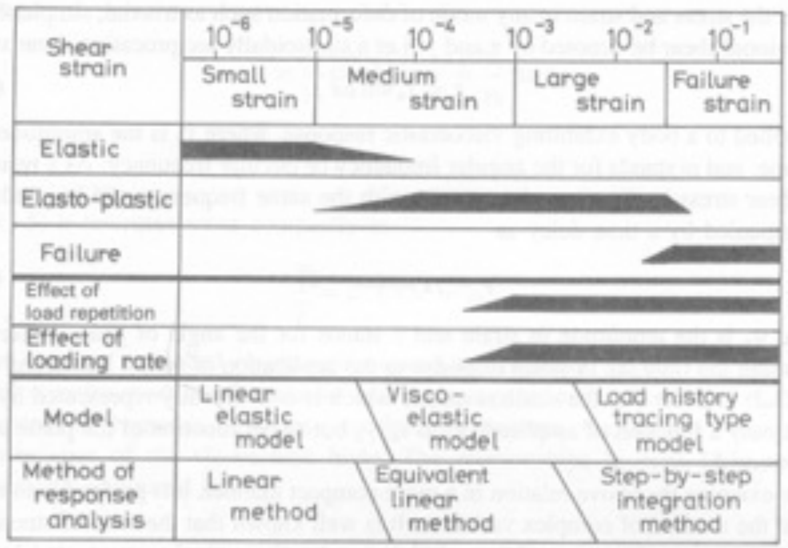
Site amplification is different for strong ground motion



Why do we have this difference?

Load duration

Deformation amplitude



Note that we do not make any difference between large or small events

EPRI modulus reduction and damping curves