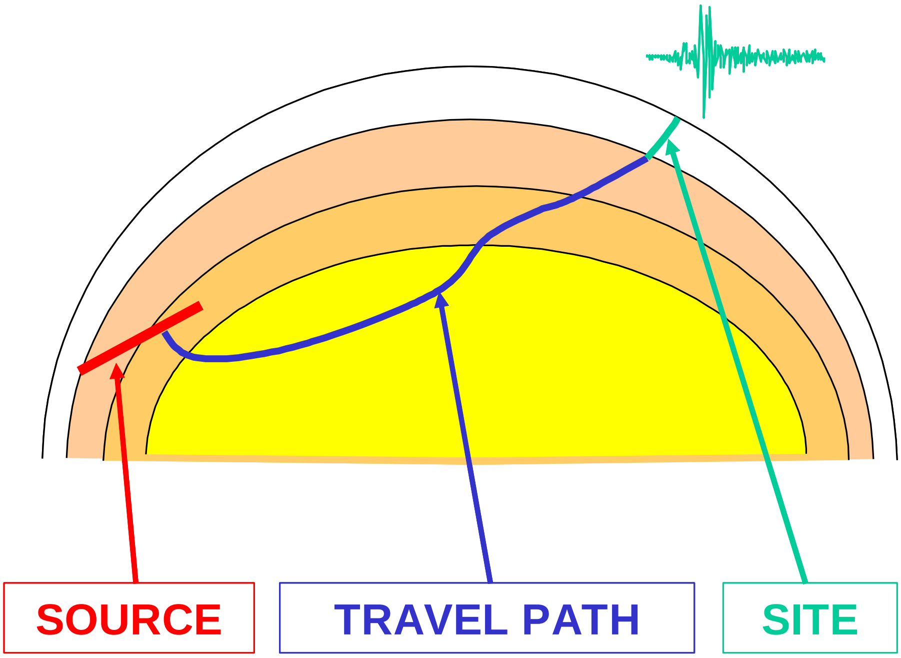
FACOLTA’ DI INGEGNERIA DELL’UNIVERSITA’ DEGLI STUDI ROMA III

Laurea specialistica in protezione del territorio dai rischi naturali

Corso di costruzioni in zona simica
Modulo di determinazione della pericolosità sismica



F.Sabetta, N. Fiorini

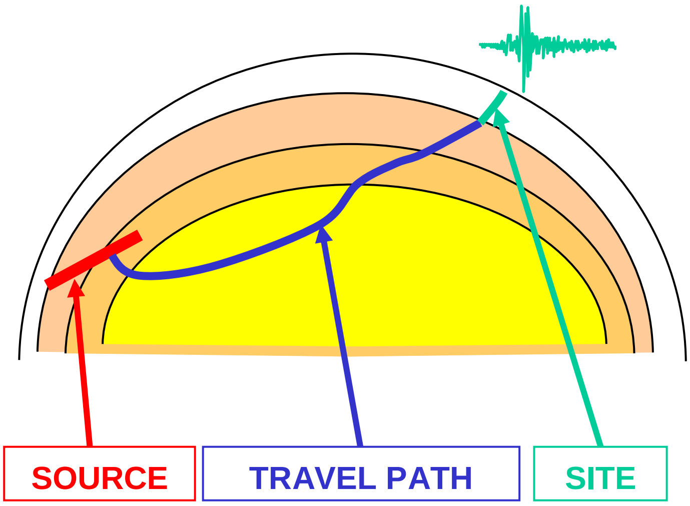
6. Caratterizzazione ingegneristica del moto del terreno. Effetti di sito

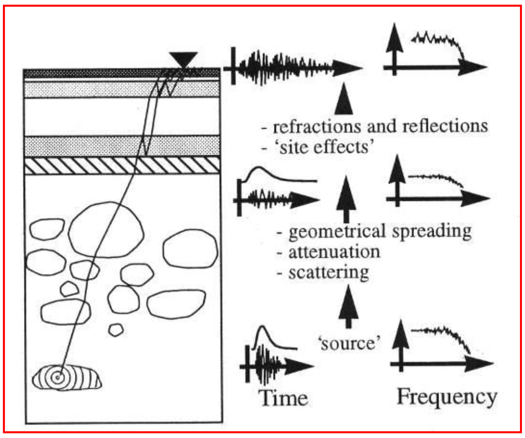
Anno accademico 2017/18

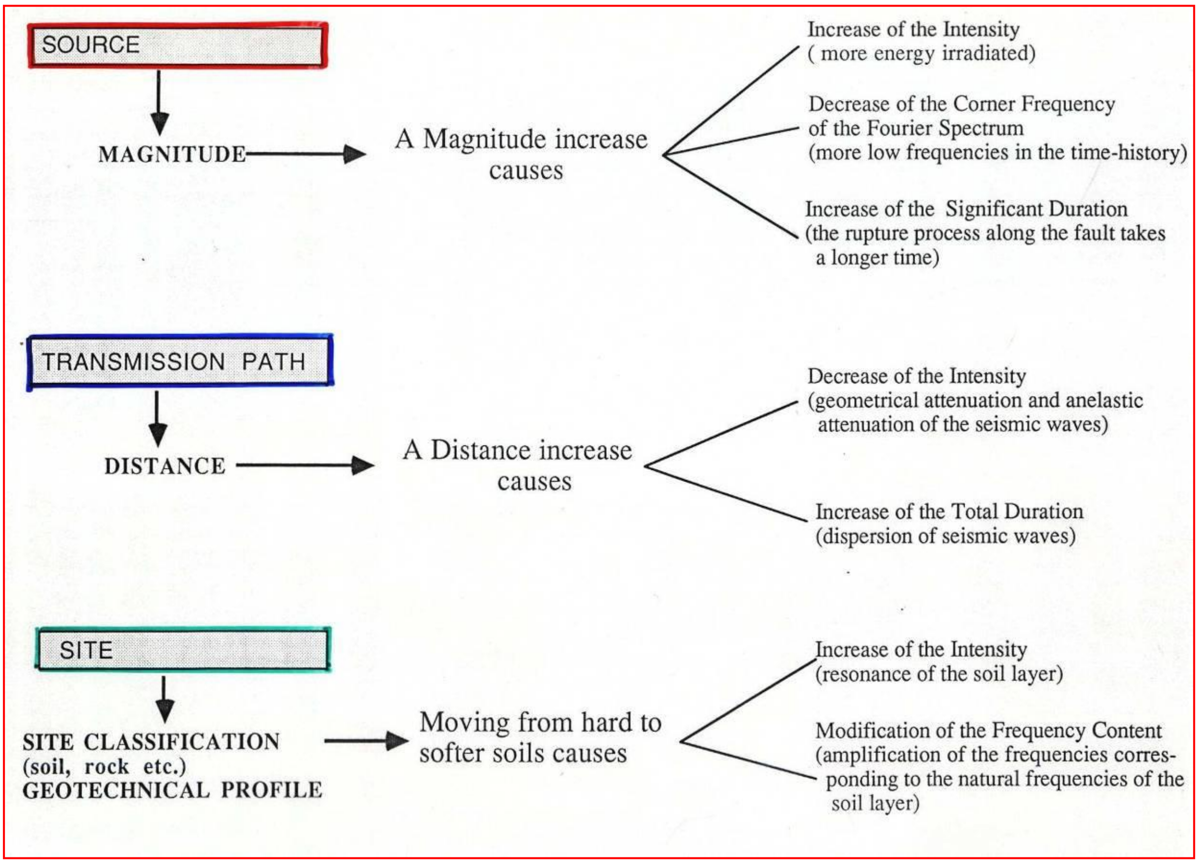
SUMMARY

Damage potential: amplitude, frequency content, duration

Main factors affecting strong ground motion







SOURCE

MAGNITUDE → A Magnitude increase causes

- Increase of the Intensity (more energy irradiated)
- Decrease of the Corner Frequency of the Fourier Spectrum (more low frequencies in the time-history)
- Increase of the Significant Duration (the rupture process along the fault takes a longer time)

TRANSMISSION PATH

DISTANCE → A Distance increase causes

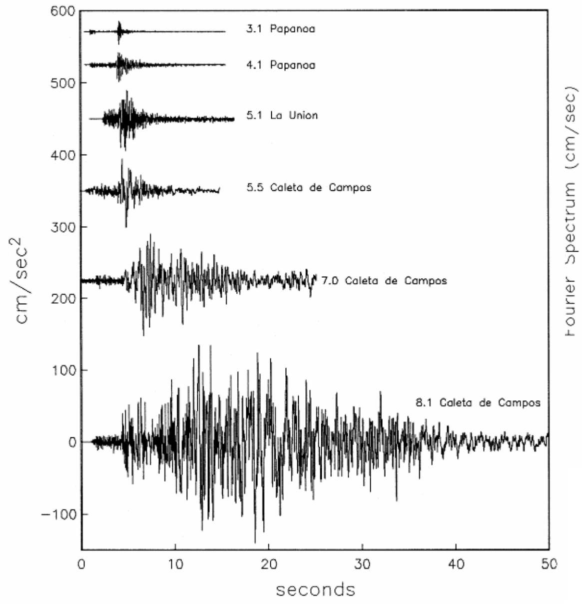
- Decrease of the Intensity (geometrical attenuation and anelastic attenuation of the seismic waves)
- Increase of the Total Duration (dispersion of seismic waves)

SITE

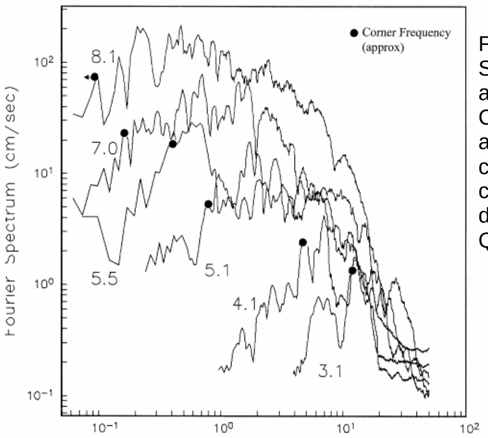
SITE CLASSIFICATION (soil, rock etc.) GEOTECHNICAL PROFILE → Moving from hard to softer soils causes

- Increase of the Intensity (resonance of the soil layer)
- Modification of the Frequency Content (amplification of the frequencies corresponding to the natural frequencies of the soil layer)

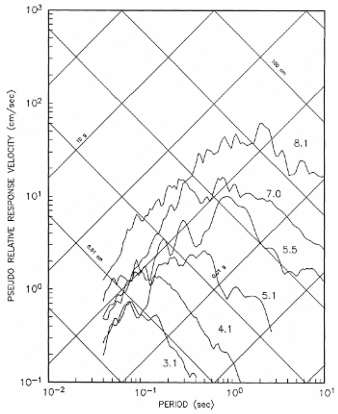
Effects of magnitude



Accelerograms recorded in Guerrero, Mexico, from earthquakes of several magnitudes (from Anderson and Quaas, 1988)



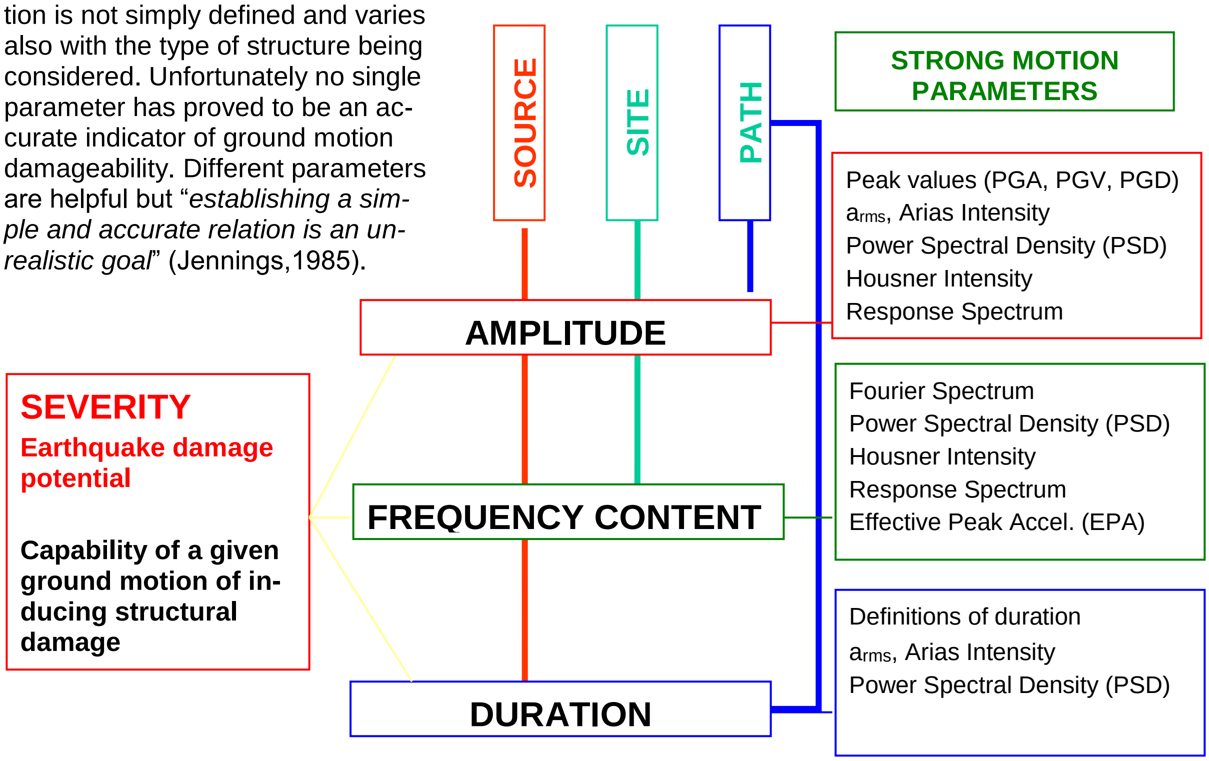
Fourier Ampl. Spectra of the accelerograms. Circles identify approximate corner frequency. (from Anderson and Quaas, 1988)



PSV response spectra of the accelerograms. (from Anderson and Quaas, 1988)

Damage potential

The severity of a given ground motion is not simply defined and varies also with the type of structure being considered. Unfortunately no single parameter has proved to be an accurate indicator of ground motion damageability. Different parameters are helpful but "*establishing a simple and accurate relation is an unrealistic goal*" (Jennings,1985).



SOURCE

SITE

PATH

STRONG MOTION PARAMETERS

AMPLITUDE

Peak values (PGA, PGV, PGD)
a_{rms}, Arias Intensity
Power Spectral Density (PSD)
Housner Intensity
Response Spectrum

FREQUENCY CONTENT

Fourier Spectrum
Power Spectral Density (PSD)
Housner Intensity
Response Spectrum
Effective Peak Accel. (EPA)

DURATION

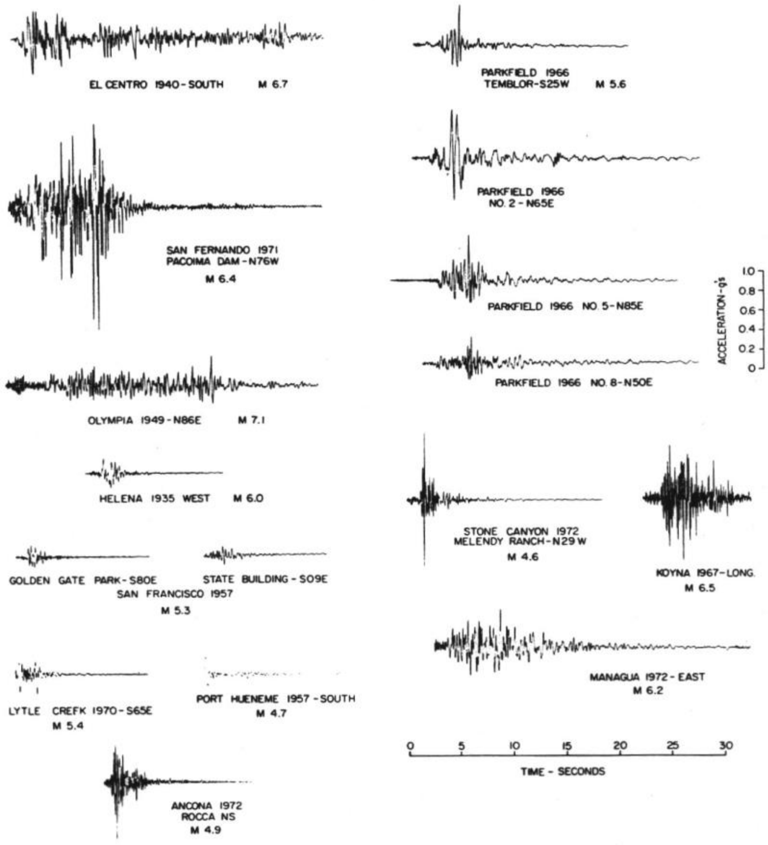
Definitions of duration
a_{rms}, Arias Intensity
Power Spectral Density (PSD)

SEVERITY

Earthquake damage potential

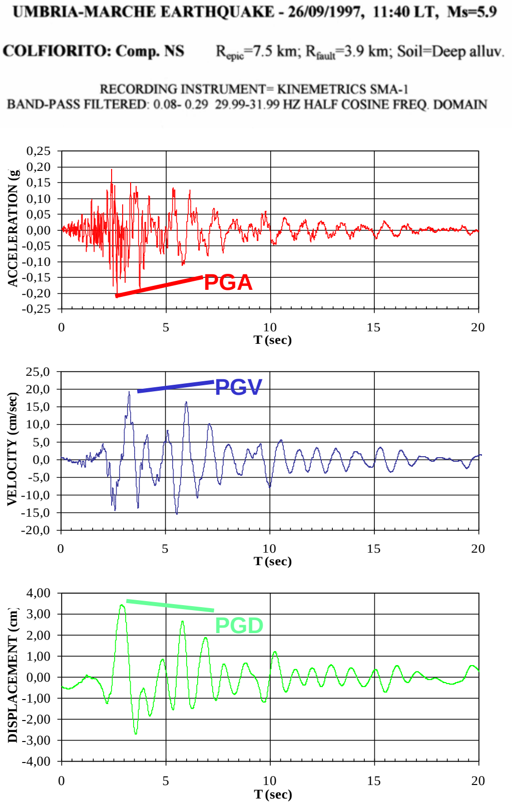
Capability of a given ground motion of inducing structural damage

Variability of ground motion



Accelerograms from various earthquakes and recording sites, illustrating the variability in the nature of strong ground-motion (Hudson, 1979).

Peak values



The simplest, most easily obtained and <u>most widely used</u> strong-motion parameter is the <u>peak ground acceleration (PGA)</u>. The PHA (Horizontal) occurs in most recordings in the S wave portion with <u>predominant frequencies between 3 and 8 Hz</u>.

The PVA (Vertical) occurs sometimes in the P wave and sometimes in the S waves with predominant frequencies between 5 and 20 Hz.

PGA relates only to one isolated peak within a record and it's a rather poor parameter for characterising the motion. At the same time, it does not correlate well with the damage potential of the shaking, although it does seem that a <u>value of above 0.2*g* is required for the motion to be potentially damaging to engineered structures.</u>

The peak values of <u>ground velocity (PGV)</u> and <u>ground displacement (PGD)</u> can also be used to characterise the ground motion.

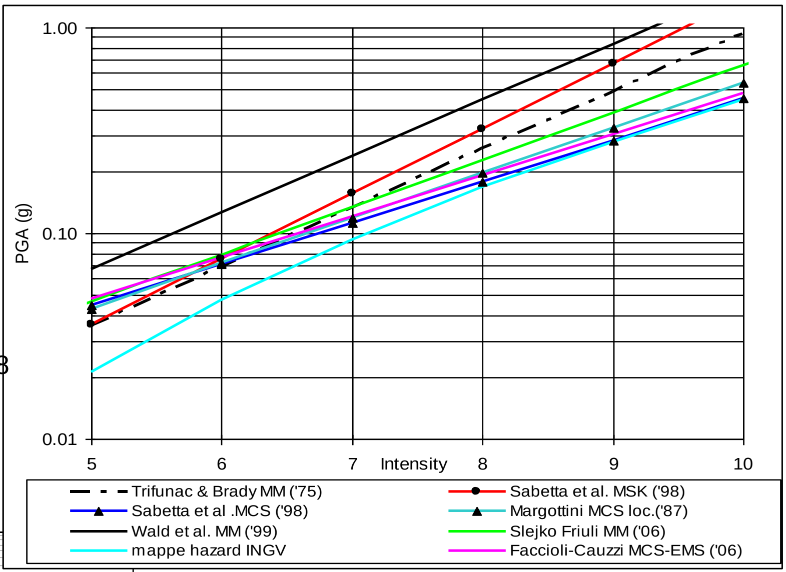
PGV is a better indicator of damage potential than PGA. It is associated with longer period motion and can be easily associated with energy because kinetic energy is proportional to the square of velocity.

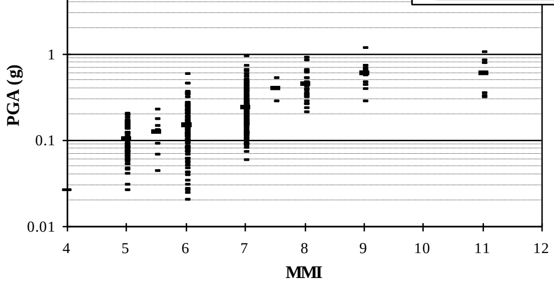
Peak displacements are associated with the lower frequencies and are often difficult to determine accurately due to signal processing errors (long period noise).

Correlation PGA-Intensity

PGA can be correlated to macroseismic intensity. Although data are very scattered and correlations are very fare from precise, they are very useful when only intensity information is available (pre-instrumental earthquakes)

PGA(g) =10^(-1.33+0.2*IMCS)/9.8
(Cauzzi Faccioli 2006)





Vertical accelerations have received less attention than horizontal ones, because the gravity-induced vertical force is already considered in design.

<u>For engineering purposes PVA is often assumed to be 2/3 of PHA</u>. The ratio PVA/PHA has been recently observed to be greater than 2/3 for near source moderate/ large earthquakes and less than 2/3 for large distances.

Arias Intensity and Root Mean Square Acceleration

The damage caused to structures by ground shaking is ultimately related to the energy in the motion that is input to the structure; if the structure cannot dissipate this energy through damping, then it will be absorbed through cracking and inelastic deformations. <u>Therefore, parameters that are related to the energy in the accelerogram can be useful indicators of the destructive potential of the ground motion</u>.

One such parameter is the ***<u>Arias intensity, AI</u>*** (Arias, 1970). The Arias intensity is defined as:

$$\mathbf{AI} = \frac{\pi}{2g}\int_0^T a^2(t)dt = \frac{\pi}{2g}\int_{-\infty}^{\infty} a^2(t)dt = \frac{1}{4g}\int_{-\infty}^{\infty} A^2(\omega)d\omega = \frac{1}{2g}\int_0^{\omega_n} A^2(\omega)d\omega$$

Parseval's theorem

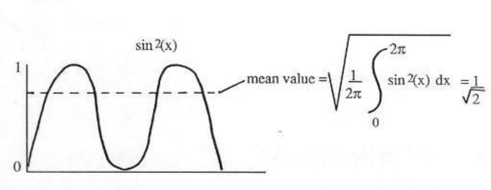
where **a(t)** is the acceleration time history of total duration **T** and **A(w)** is The Fourier Amplitude Spectrum. AI has units of velocity (cm/s) and is ***<u>proportional to the total energy</u>*** input of an infinite set of undamped linear oscillators.

Another widely used parameter is the ***root-mean-square acceleration, a_{rms}***

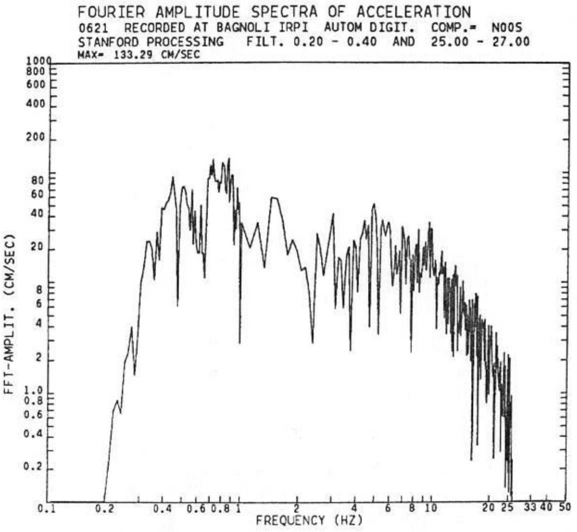
$$a_{rms} = \sqrt{\frac{1}{T_d}\int_0^{T_d} a^2(t)dt}$$

If the significant duration Td is considered equal to the total duration T

$$AI = \frac{2g}{\pi} T \cdot a_{rms}^2$$



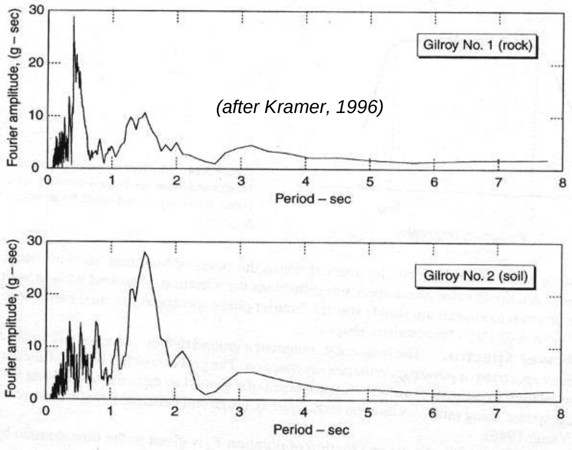
Fourier Spectra



Fourier Amplitude Spectrum (FAS)

Phase Spectrum

$$F(\omega) = |A(\omega)|e^{i\phi(\omega)} = \int_{-\infty}^{+\infty} f(t)e^{-i\omega t}dt$$

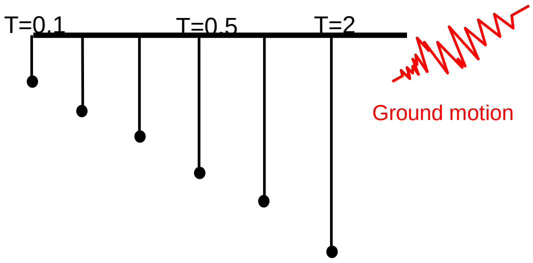


(after Kramer, 1996)

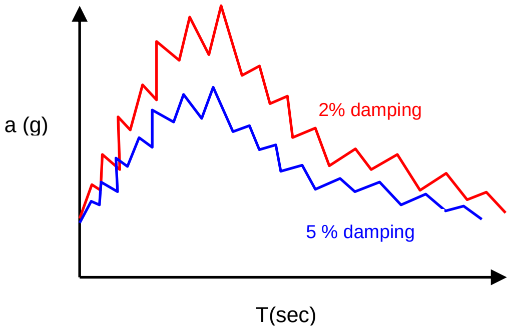
Since phase angles control the times at which the peaks of motion occur, the Fourier phase spectrum influences the variation of ground motion with time. Fourier phase spectra do not display characteristic shapes.

Response Spectra

The response spectrum is the most important characterisation of seismic ground-motion in earthquake engineering and forms the basis for most design and analysis of structures.

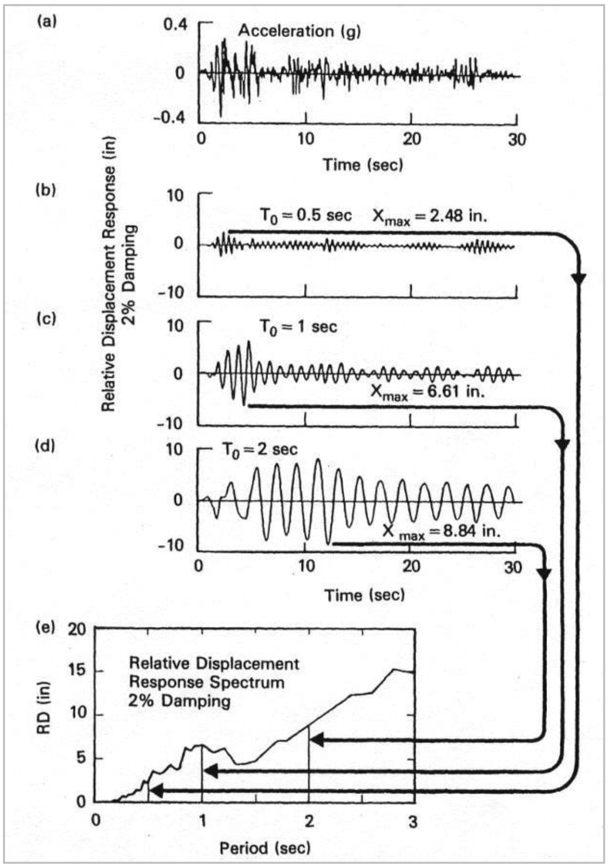


If a series of linear damped oscillators (SDOF), with a given level of damping, are all subjected to an acceleration time-history acting at their base, each mass will respond differently according to its natural period.

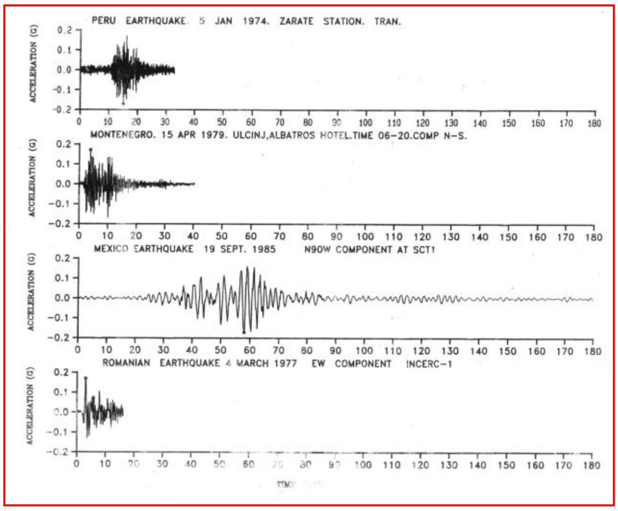


The response spectrum represents the maximum absolute response amplitudes of each oscillator, expressed in terms of displacement, velocity, or acceleration, plotted as a function of the period or the natural frequency of the oscillators for different levels of structural damping.

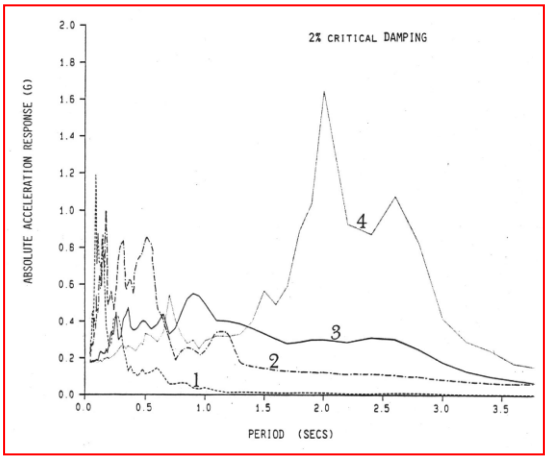
For reinforced concrete structures it is usually assumed that the damping can be taken as 5% of critical.



Response spectra reflect strong ground motion characteristics indirectly since they are filtered by the response of the oscillators. The amplitude, frequency content and to a lesser extent, duration of the input motion all influence spectral values.



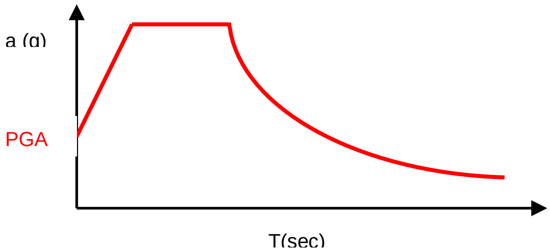
Four accelerograms with identical values of PGA (Bommer, 2001a).



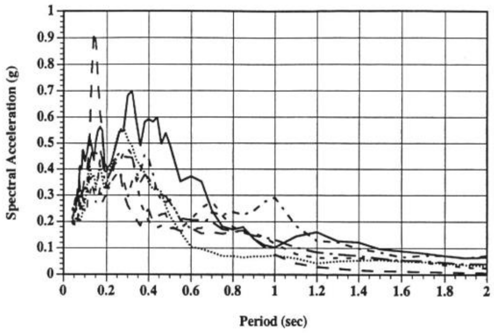
Elastic response spectra of absolute acceleration of four accelerograms: 1 – Peru 1974, 2 – Yugoslavia 1979, 3 – Romania 1977, 4 – Mexico 1985 (Bommer, 2001a).

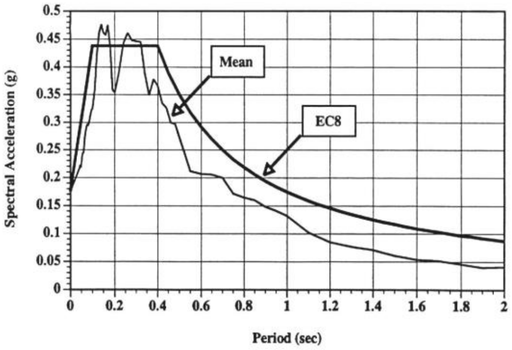
Three different spectra can be defined according to how the response of each SDOF is measured: **relative displacement, relative velocity or absolute acceleration**. At zero period the spectra of relative displacement and relative velocity are equal to zero since for an infinitely rigid oscillator there is no vibration. At zero period the relative acceleration is also zero and the absolute acceleration is equal to the maximum acceleration of the ground. **This is a very important point to grasp: the response spectrum of absolute acceleration anchors at PGA at T=0**, as can be appreciated from the above Figure: despite their very significant differences, all of the spectra converge to 0.18*g* at the period T=0.

Design spectra



Envelope of elastic response spectra obtained from strong ground motion recordings used to design buildings, plants and **facilities.**

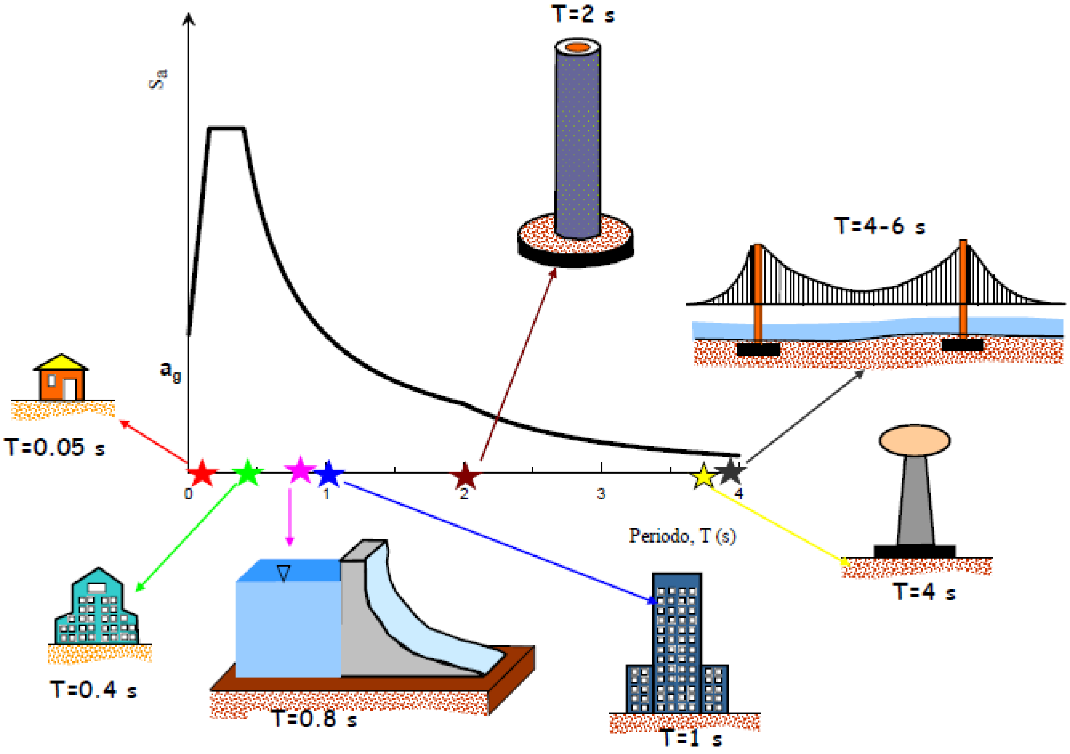




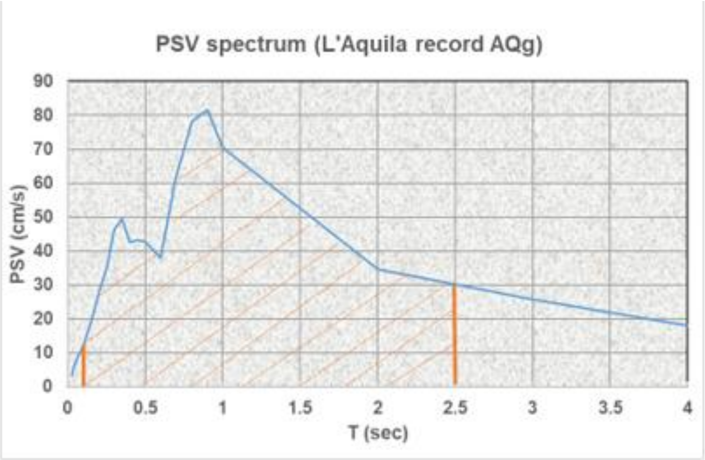
For design purposes, it is desirable to obtain shapes that represent the general shape of the spectra, either the envelope of the peak ordinates or their average. Such a smoothed spectral form can be obtained by collecting several records from similar sites and from earthquakes of comparable size, then normalising them by linear scaling so that they anchor to the same value of PGA. By taking the average ordinate at each period it is possible to obtain a smooth spectral shape that is representative of the site conditions corresponding to the accelerograms.

It is then possible to obtain the spectrum for a particular design situation by estimating the design value of PGA and then anchoring the smoothed spectral shape to this value. This is in fact the procedure used in most seismic design codes

Fundamental period of different structures



Housner Intensity



$$HI(\xi)=\int_{0.1}^{2.5} PSV(T,\xi)dT$$

Housner Intensity (measured in cm) is a parameter showing a good correlation with the damage potential of a given ground motion. The damping ξ is generally fixed at 5%. The limits of integration 0.1-0.5 seconds include the fundamental oscillation period of the majority of buildings. They can be varied according to the particular building typologies considered

Duration

The importance of strong-motion duration in earthquake engineering is the focus of several research projects and a topic of much debate. **Duration becomes particularly critical in non-linear structural analysis, when strength or stiffness degradation occurs, and in the evaluation of liquefaction potential due to the increase of porewater pressure in saturated soils.**

The response spectrum gives no information about the strong-motion duration because the linear oscillators reach the maximum amplitude after a small number of cycles (3-10) and so the response spectrum is the same regardless the duration of motion

Bracketed and Uniform Duration

For engineering purposes only the strong motion portion of the accelerogram is of interest. The problem is that there is no universally accepted definition of duration and reference is frequently made to it without specifying how the duration is defined. A good review of different definitions of duration can be found in Bommer and Martínez-Pereira (1999).

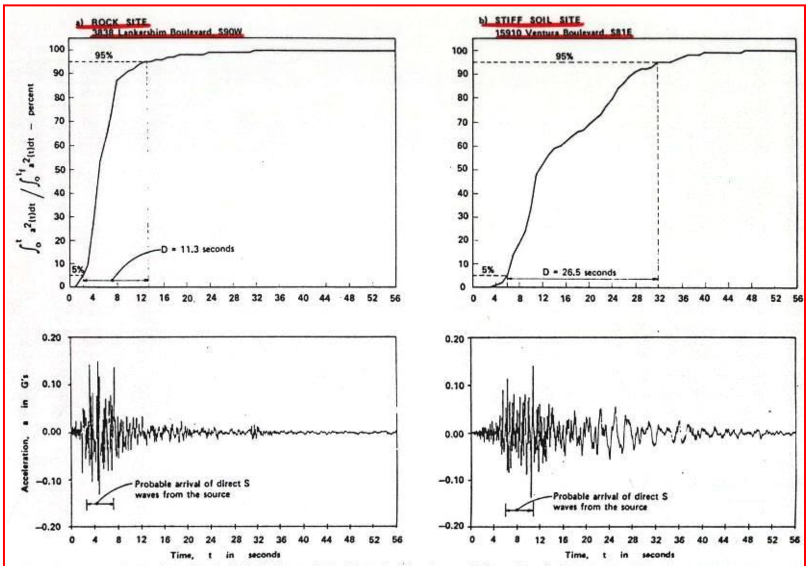
The main definitions that have been put forward can be grouped into three categories: ***bracketed***, ***uniform*** and ***significant*** durations.

The ***bracketed duration*** (Bolt, 1969) is defined as the **time interval between the first and last exceedances of a defined threshold level a_o** of acceleration (**usually 0.05 g**). A disadvantage of this definition is the subjectivity in the choice of a_o (it can be absolute or relative e.g. 10%, of PGA).

The ***uniform duration*** (Sabetta, 1983; Sarma &Casey, 1990) is explained in a similar way to the bracketed duration except that instead of being the complete interval between the thresholds it is defined as the **sum of the intervals during which the acceleration is above the threshold a_o**. This definition is less sensitive to the threshold level than the bracketed duration but it has the disadvantage of not defining a continuous time window during which the shaking can be considered strong.

Significant Duration and Husid ratio

The ***significant duration*** is determined from the build up of Arias intensity: Husid (1969) proposed to plot the build up of AI versus time with the use of a normalized variable known as ***Husid Ratio H(t)=100xAI(t)/Ai***. The Trifunac and Brady (1975) widely used definition is is based on the time interval between the points at which 5% and 95% of the total AI has been recorded.

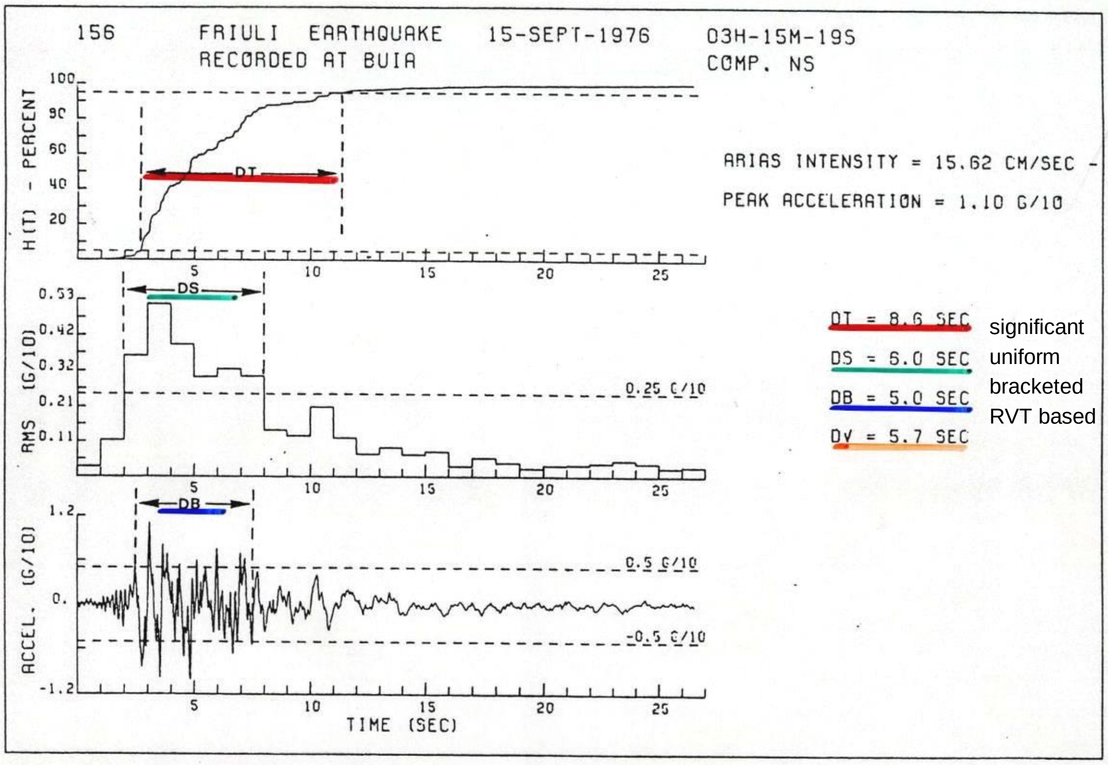


Comparison of typical Husid plots and significant durations for a rock site and a soil site (1971 San Fernando earthquake).

from Dobry et Al. (1978)

A disadvantage of this definition is that it is “cumulative” and without threshold and can result in an overestimation for records of small amplitude or with small sub-events occurring after the the main shock.

Comparison of different definitions of duration

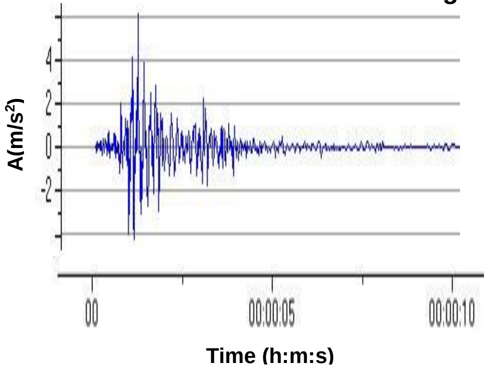


DT = 8.6 SEC significant
DS = 6.0 SEC uniform
DB = 5.0 SEC bracketed
DV = 5.7 SEC RVT based

DT = Trifunac and Brady (1975) Duration ; DS = Sabetta (1983) Duration;
DB = Bolt (1974) Duration ; DV = Vanmarcke and Lai (1980) Duration.

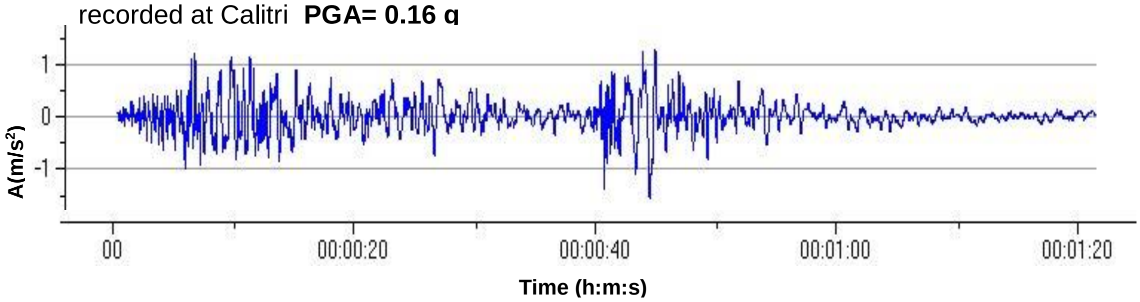
Effect of Duration on damage potential

Ancona Earthquake 6/14/1972
recorded at Rocca **PGA= 0.62 g**



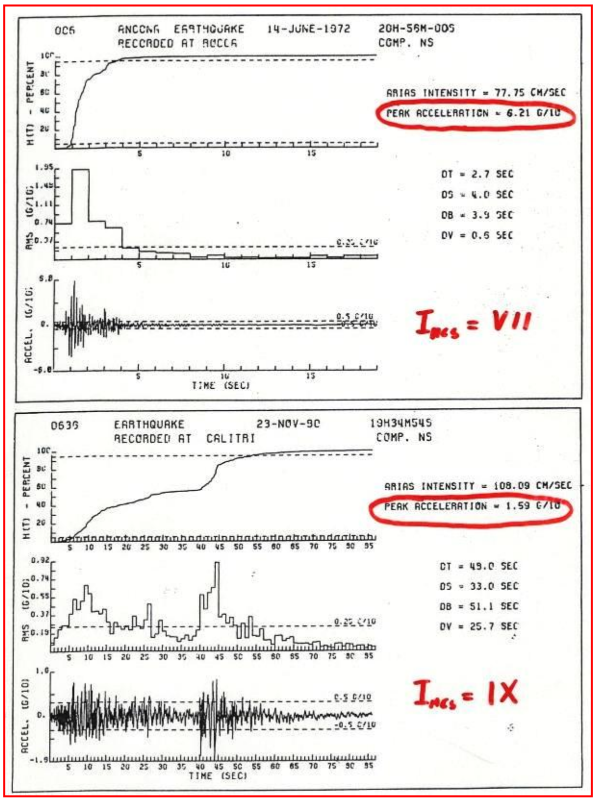
Which accelerogram carries the highest damage potential ?

Irpinia Earthquake 11/23/1980
recorded at Calitri **PGA= 0.16 g**



Ms=4.6
Repi= 8 km
Site= rock

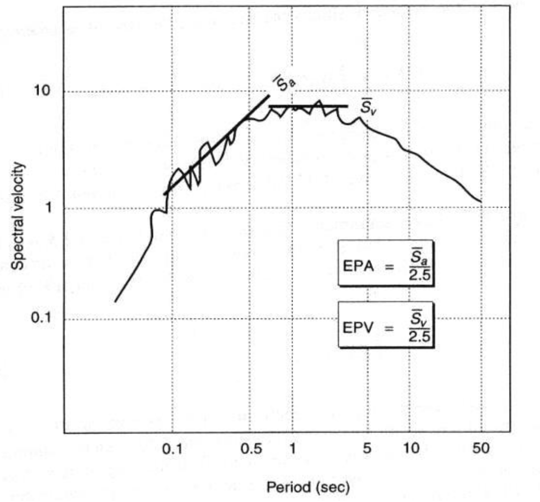
Ms=6.9
Repi= 18 km
Site= soil

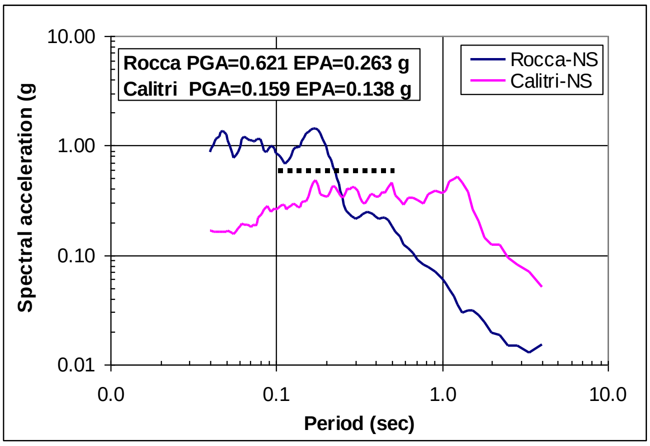


Effective peak acceleration (EPA)

The concept of ***effective peak acceleration (EPA)*** has been introduced to **mitigate the effect of excessively high PGA** associated to very short durations and high frequency (generally small magnitude close earthquakes) having little effect on structural damage.

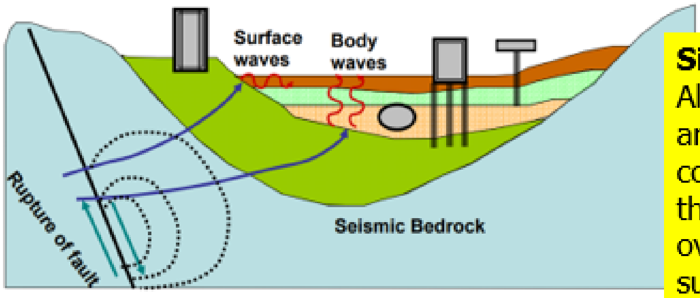
There is actually much confusion about the concept of EPA and there is no universally accepted definition, although the most widely used is that given by the Applied Technology Council (1978) as **the average spectral acceleration over the period range 0.1 - 0.5 sec divided by 2.5** (the standard amplification factor for a 5% damping spectrum). The ***effective peak velocity (EPV)*** was defined as **the average spectral velocity at a period of 1 sec divided by 2.5**. EPA and EPV have been used in the specification of smoothed design response spectra in building codes.





Effects of local site conditions on ground motion

Schematic figure showing wave propagation from fault to ground surface



Site response or **site effects**: All of the changes that affect amplitude, duration and frequency content of a ground motion, on the bedrock , while it traverses overlying soil layer towards the surface (S).

Earthquake recordings at soil surface include "information"

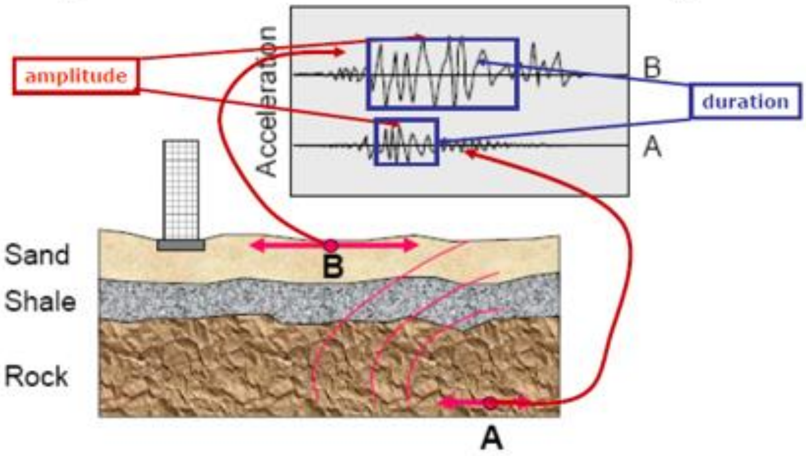
1. the source activation (fault rupture)
2. the propagation path of seismic energy
3. the effect of local geology at the recording site

Local site conditions can profoundly influence all of the important characteristics (amplitude, frequency content, and duration) of strong ground motion.
The extent of their influence depends on:

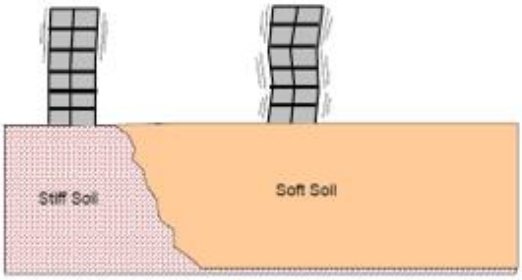
- the geometry and material properties of the subsurface materials,
- site topography
- the characteristics of the input motion

Moreover the **local geology** is responsible for significant amplification and spatial variation of surface ground motion and irregular geographical distribution of damages

Soil formations and topography modify the characteristics (**amplitude, frequency content and duration**) of the incoming wavefield having as a result the amplification or deamplification of ground motion

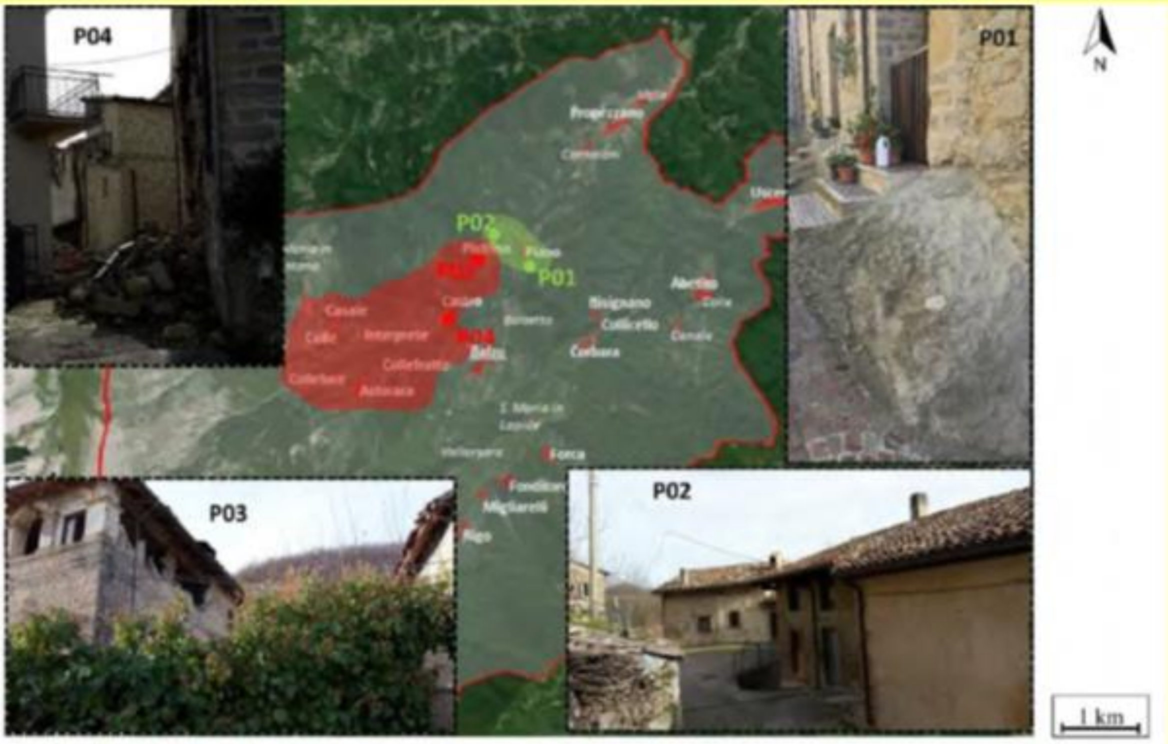


Structures founded on soils, especially if soft, tend to be subjected to stronger shaking with longer-period motions



K. Pitilakis lecture notes 2007

EXAMPLES: Amatrice 2016 seismic sequence



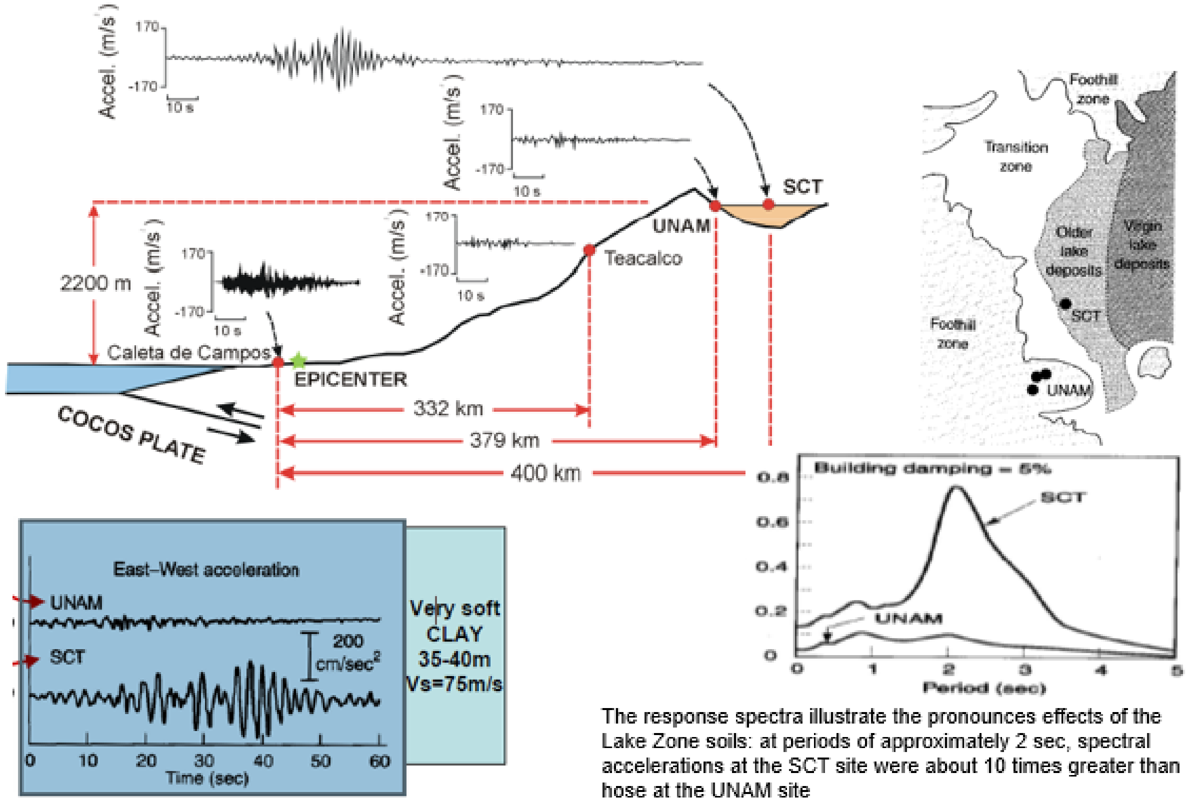
Spatial distribution of different building damage (from level 1 to 4) due to local site effect across the municipality of Montegallo

Sextos et al . (2018). Local site effects and incremental damage of buildings during the 2016 Central Italy 2 earthquake sequence

EXAMPLES: Mexico City, 1985 earthquake

Mexico City, 1985 Ms = 8.1

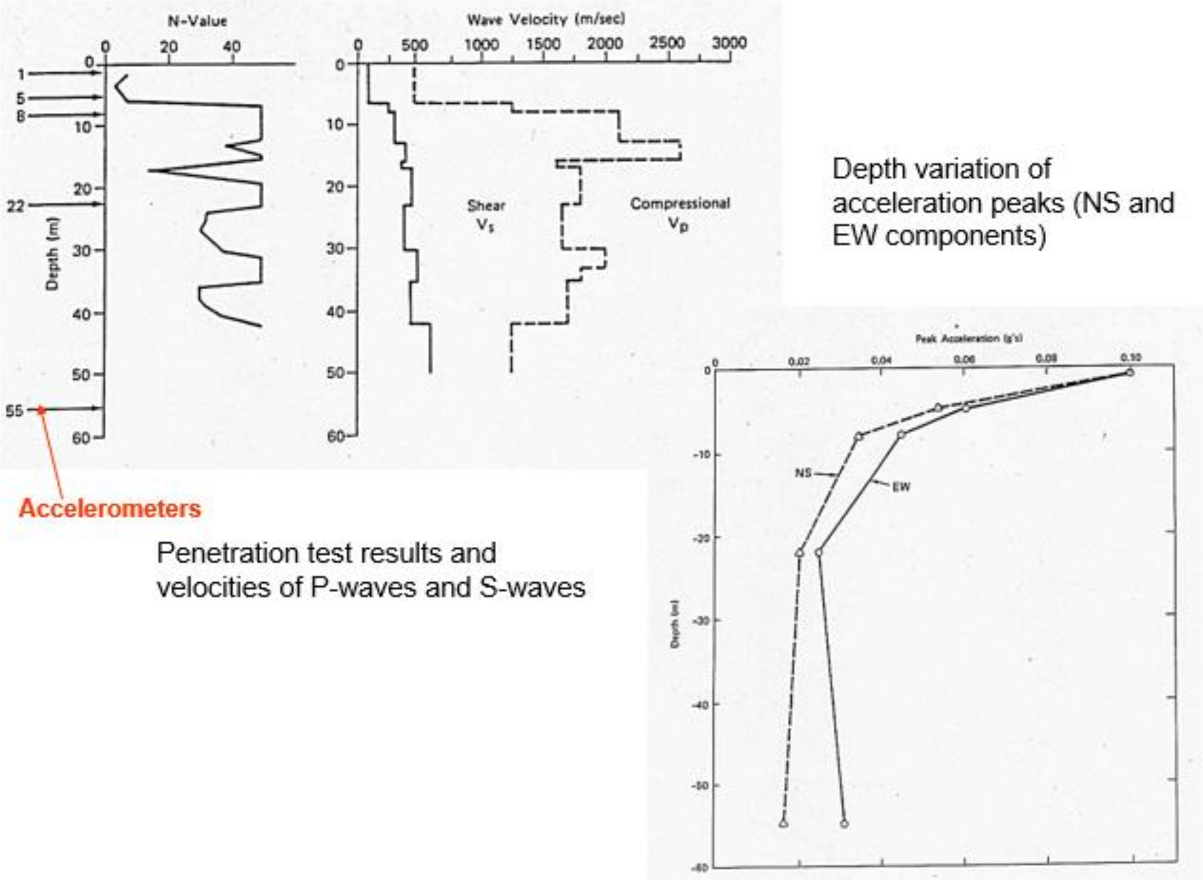
cause only moderate damage in the vicinity of the epicenter but extensive damage 350 km away.



The response spectra illustrate the pronounces effects of the Lake Zone soils: at periods of approximately 2 sec, spectral accelerations at the SCT site were about 10 times greater than hose at the UNAM site

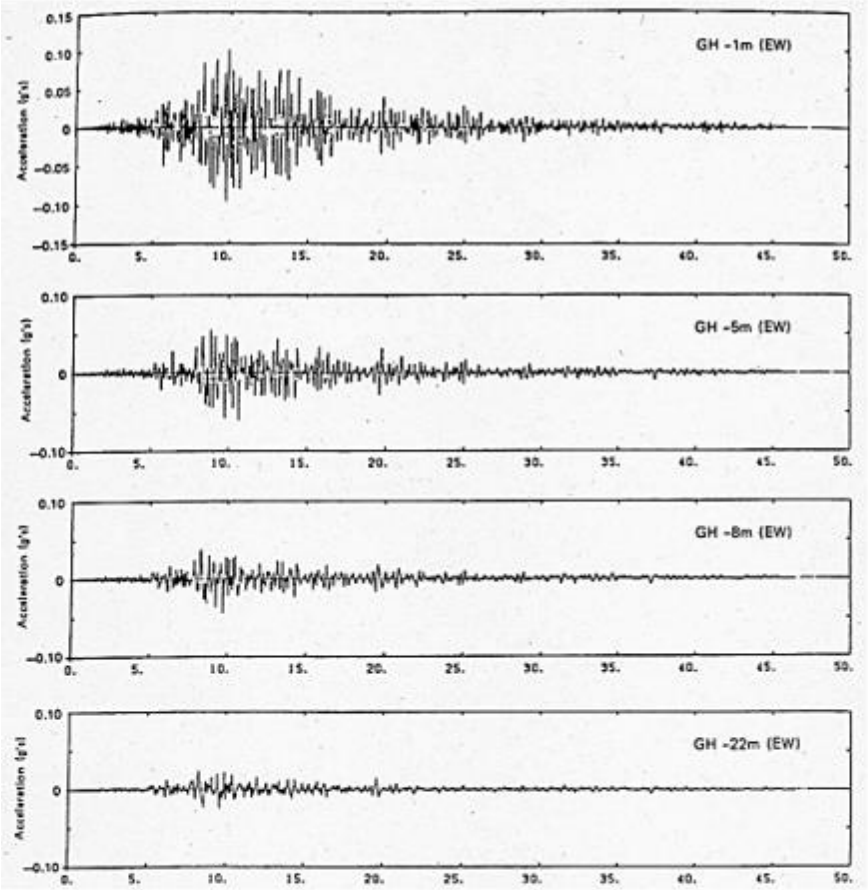
In the 1985 Mexico City earthquake, structures built on soft soil sediment sustained severe damage

EXAMPLES: vertical accelerometric array of Nairmasu (Japan)



Depth variation of acceleration peaks (NS and EW components)

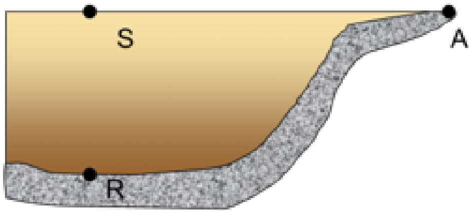
Penetration test results and velocities of P-waves and S-waves



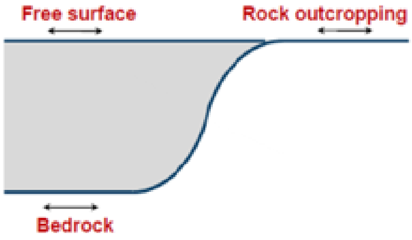
Accelerometric records performed at different depths

Evaluation of site effects

The evaluation of the site effects is mainly a comparison between the different quantities (accelerations and amplitude) estimated at the surface S and the ones evaluated at the bedrock R



- Free surface motion
  = the motion at the surface of a soil deposit
- Bedrock motion
  = the motion at the base of a soil deposit
- Rock outcropping motion
  = the motion at a location where bedrock is exposed at the ground surface

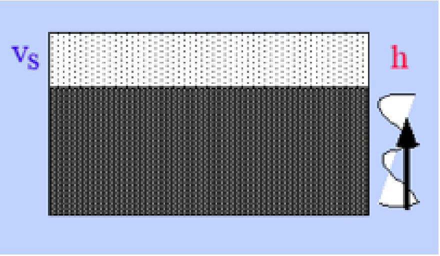


$$\text{Amplification} = \frac{\text{Free Surface}}{\text{Bedrock}} \qquad \text{Amplification} = \frac{\text{Free Surface}}{\text{Outcrop}}$$

The amplification can be evaluated:

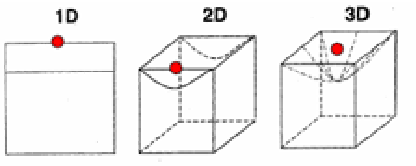
1. Comparing the ground motion of the soil deposit (S) with that of bedrock outcrop (A).
2. Knowing from geotechnical measures the properties (velocity Vs, shear modulus G, damping D) of the soil deposit and using a finite element code to estimate the amplification

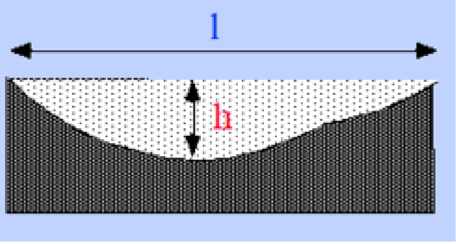
1D, 2D, 3D Models



1-D model, parallel layers, vertically propagating seismic waves

Resonance frequency = $V_s / 4H$





2-D, 3-D model, angle of incidence of seismic waves

Multiple reflection and waves constructive interference, production of surface waves in alluvial valleys, topographic effects.

The maximum effect occurs when l/H is =1 and it is comparable with the wave length of incident seismic waves.

Properties of surface materials that affect ground motion

IMPEDANCE

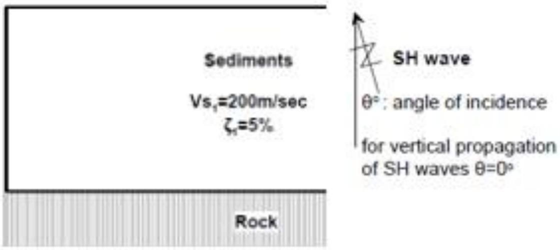
Impedance = the product of the density (ρ), the shear wave velocity (Vs) and the cosine of the angle of incidence which is defined as the angle between the vertical and the direction of seismic wave propagation

$$I = \rho \cdot Vs \cdot \cos\theta$$

$$\cos\theta \cong 1$$

$$\Downarrow$$

$$I = \rho \cdot Vs$$



When seismic waves meet a decrease in impedance below the earth's surface, an increase in their amplitude is observed due to **resonance** as seismic waves are trapped in this layer and begin to reverberate.

The change in impedance is expressed with the impedance contrast

$$C = \frac{I_2}{I_1} = \frac{\rho_2 \cdot Vs_2}{\rho_1 \cdot Vs_1}$$

DAMPING

damping = Absorption, anelastic attenuation

- Absorption is substantially greater on soft soils than on hard rocks
- and mitigates the increase in amplitude of seismic motion due to resonance

Part of the elastic energy of a traveling wave is always converted to heat.

Damping is often used to represent this dissipation of elastic energy.

Mitigates this increase in amplitude and it tends to be greater on soft soils than on hard rocks.

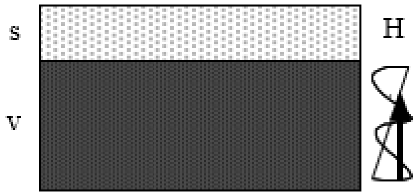
At higher frequencies the impact of absorption can be very severe while at low frequencies it is less so.

Frequency domain features of the resonance phenomenon

Resonance occurs as some of the seismic waves transmitted into the upper rock (or soil) layer themselves become trapped in this layer and begin to reverberate.
This effect is maximum when the reverberating waves are in phase with each other.
Resonance is a frequency dependent phenomenon.

In the simplest case the maximum occurs for waves **whose wavelength is four times the thickness of the layer** in which the seismic waves are trapped.
For s-waves the frequency which is amplified the most (**resonance frequency**) is that which is equal to **V_s/4H**,
where **v_s** is the shear wave velocity of the layer and **H** is its thickness.

fo = Vs /4H



1-D model, parallel layers, vertically propagating seismic waves

- One horizontal layer - 1D structures

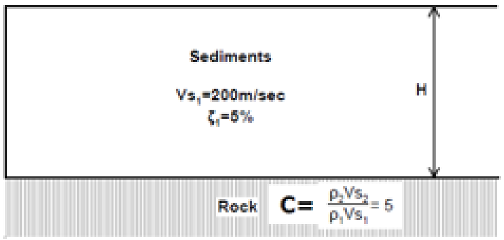
$$f_0 = \frac{Vs_1}{4 \cdot H}$$ fundamental

$$f_n = (2n+1) \cdot f_0$$ harmonics

- f_0 = 0.2Hz - 10Hz or more

very thick deposits or extremely soft materials

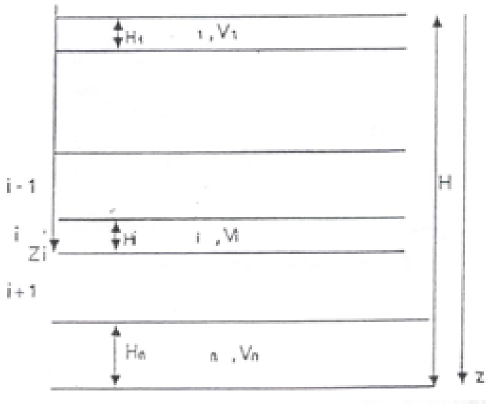
very thin layers of deposits or weathered rocks



- horizontal multi-layer 1D structures

only f_0 or T_0 can be approximated

$$f_0 = \frac{1}{T_0}$$



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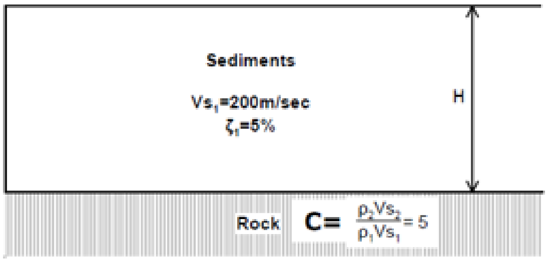
Basically the amplification of seismic waves originates from the strong contrast between the physical properties of the rocks and the overlying sediments.

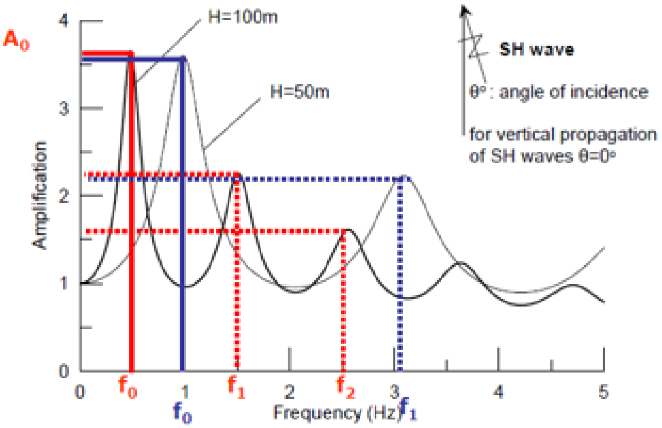
- A_0 depends on impedance contrast and material damping

$$A_0 = \frac{1}{\frac{1}{C} + 0.5 \cdot \pi \cdot \zeta_1}$$



The amplification A_0 may have values between 6 and 10. However the effect of impedance contrast is mitigated by the damping and by the nonlinear behaviour of soils.

For example de maximum amplification factor generally foreseen by the building codes is ≈ 1.4



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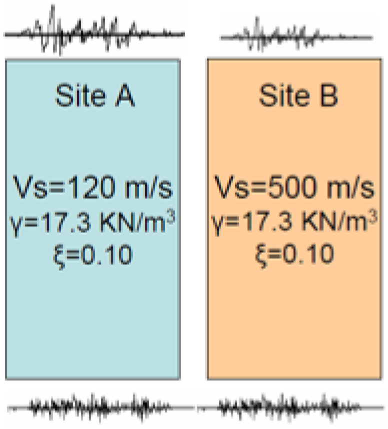

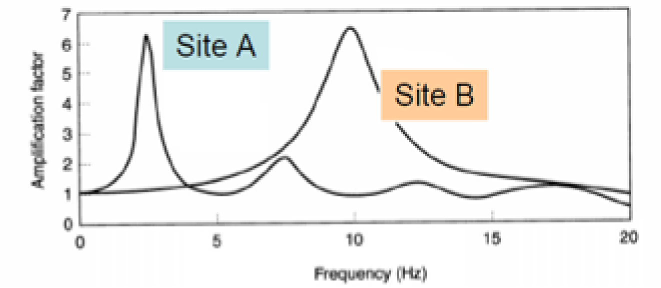

Softer Soil A will amplify low-frequency input much more strongly that will the stiffer soil of site B. At higher frequencies, the opposite behavior is expected.

Characteristic site frequency depends only on the thickness and shear wave velocity of the soil, provides a very useful indication of the period of vibration at which the most significant amplification can be expected

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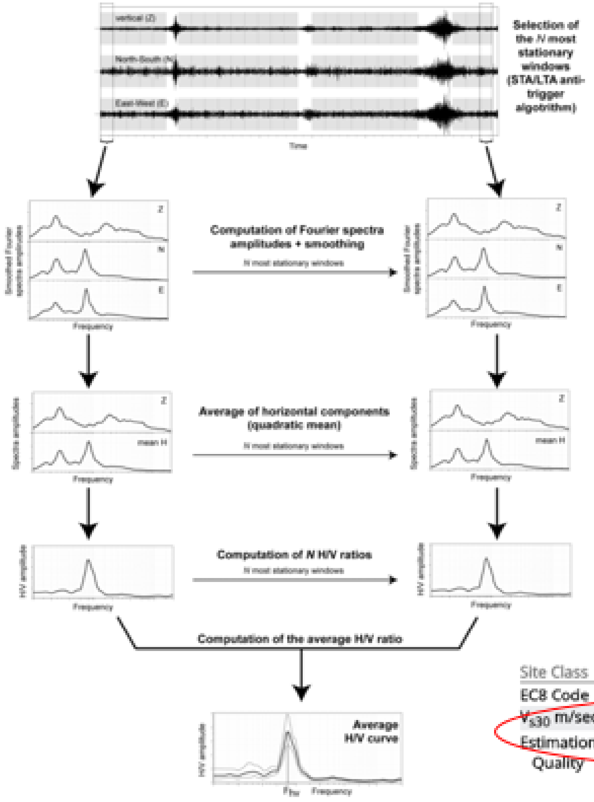
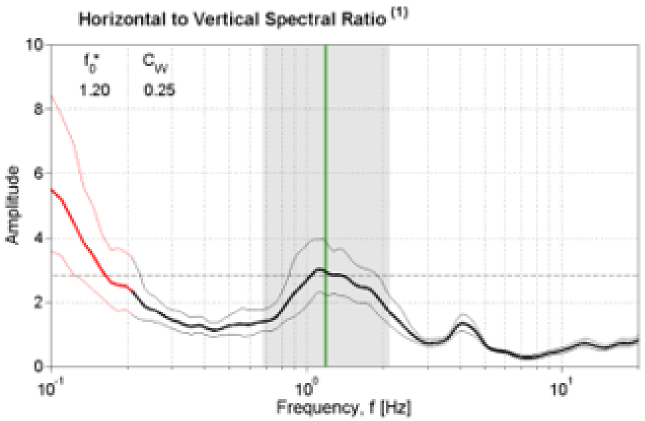
Estimation of f_0 from H/V measurements of the ambient noise (Nakamura method)

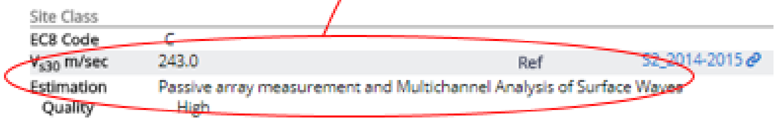
The technique proposed by Nakamura (1989), consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of the ambient noise vibrations recorded at one single station





H/V ratio measured from ambient vibrations at the Italian station of Alfonsine (Emilia Romagna)

$H=V_{S30}/4fo=243/(4*1.2)=50.6$ m



Site Class

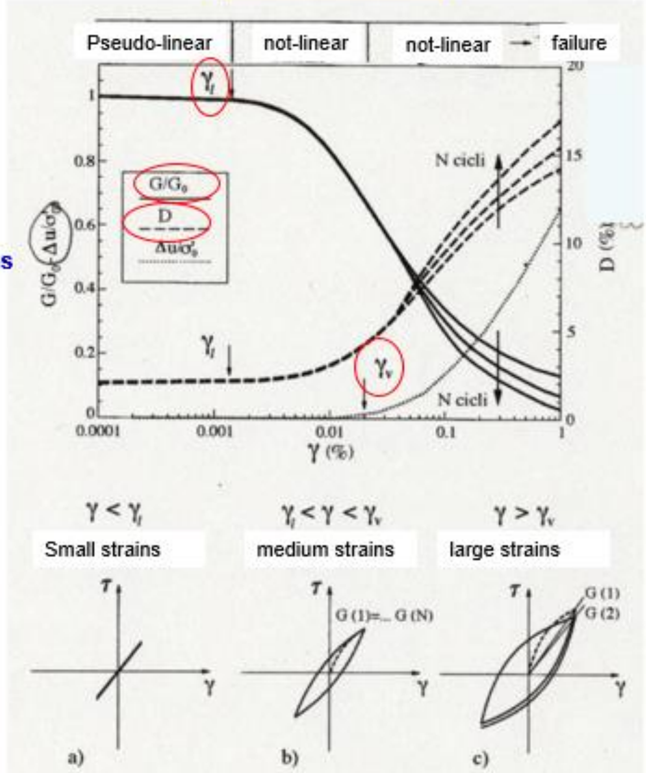
EC8 Code	C		
V_{S30} m/sec	243.0	Ref	S2_2014-2015
Estimation	Passive array measurement and Multichannel Analysis of Surface Waves		
Quality	High		

Dynamic properties of soils

G/γ D/γ curves

The stress-strain behaviour of solis can be described through two parameters:

1) **D Damping**
2) **G Shear modulus**

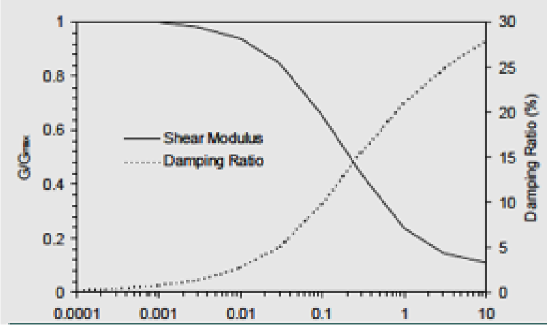


a) **Small strains**
γ_l changes its values depending on soil characteristics

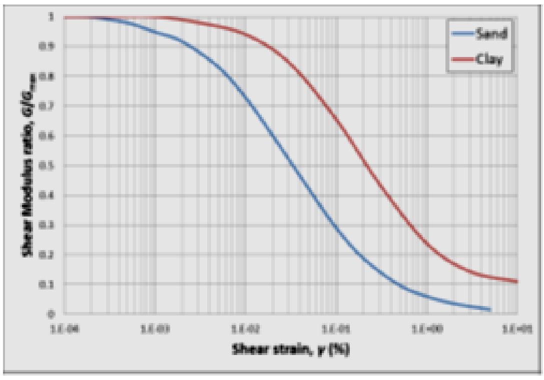
b) **Medium strains**
The soil has a steady behavior endependently from its loading history

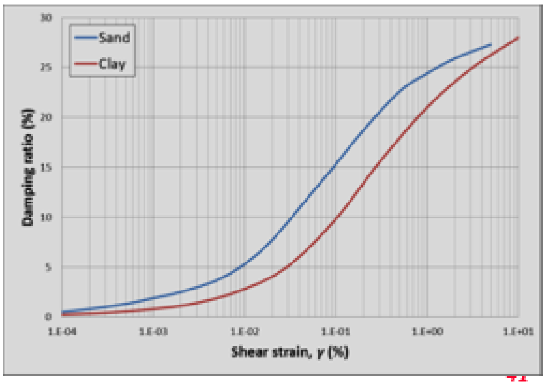
c) **Large strains**
The increase of amplitude of cyclic loading ($>\gamma_t$) the soil exhibits a general degradation with loading cycles N

under strong dynamic loading the ground becomes softer (shear strength decreases – nonlinear behavior)



Shear Modulus and Damping Curves
- Laboratory test
- Relationship from literature

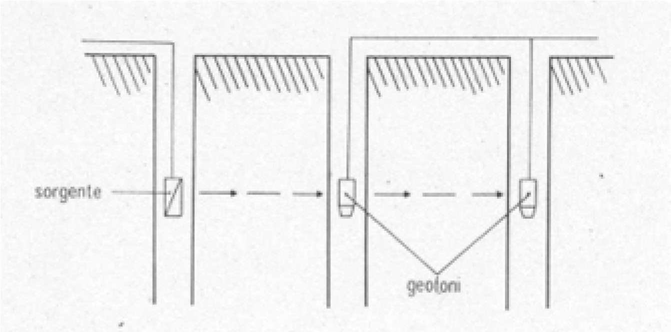




Geotechnical and Geophysical investigations of soil properties

- standard penetration test (SPT)
- cone penetration test (CPT)
- down-hole and cross-hole drillings
- Spectral Analysis of Surface Waves (SASW)
- Multichannel Analysis of Surface Waves (MASW)

There are a series of relations between SPT and N-value (N blow count) and Vs



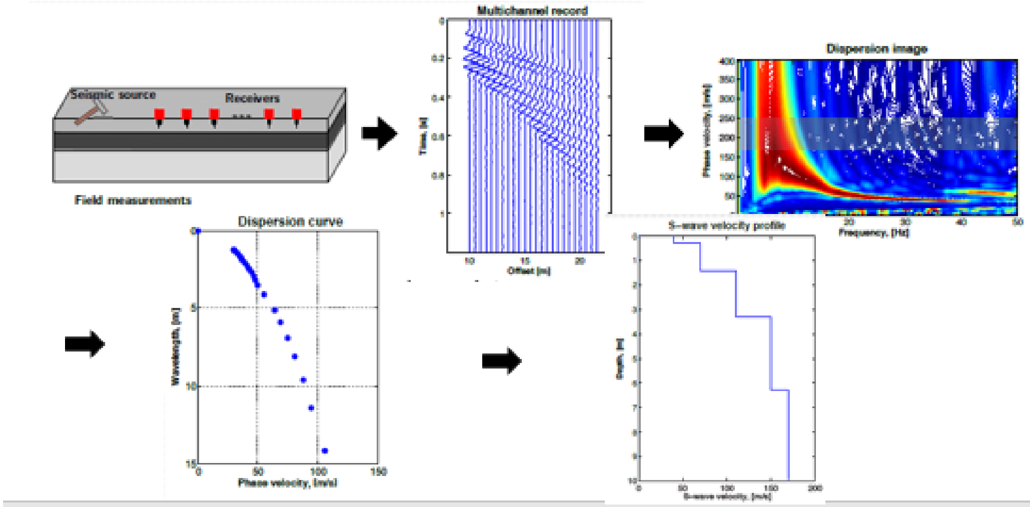
down-hole logging the travel time taken by vertically propagating shear waves from a source on the ground surface to subsurface receiver is measured along a single bore-hole

Down-hole and Cross-hole measurements of S-wave velocities.

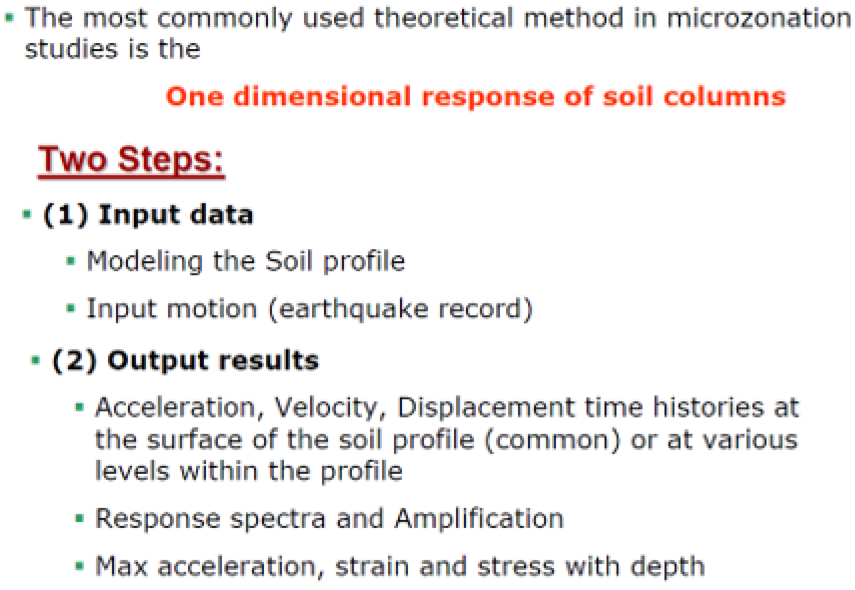
Multichannel Analysis of Surface Waves (MASW)

The shear wave velocity profile can be obtained inverting the dispersive phase velocity of recorded Rayleigh waves.
MASW surveys can be divided into active and passive surveys. In the **active MASW** method, surface waves are generated actively by impulsive or vibrating seismic sources whereas the **passive MASW** method utilizes surface waves **generated by natural sources or cultural activities, e.g. traffic** (Park et al., 2007)

The MASW method can be divided into three main steps (Park et al., 1999):
1. Data acquisition.
2. Dispersion analysis. (Determination of a Rayleigh wave dispersion curve.)
3. Inversion analysis. (Determination of a shear wave velocity profile.)



Site response analysis



- The most commonly used theoretical method in microzonation studies is the

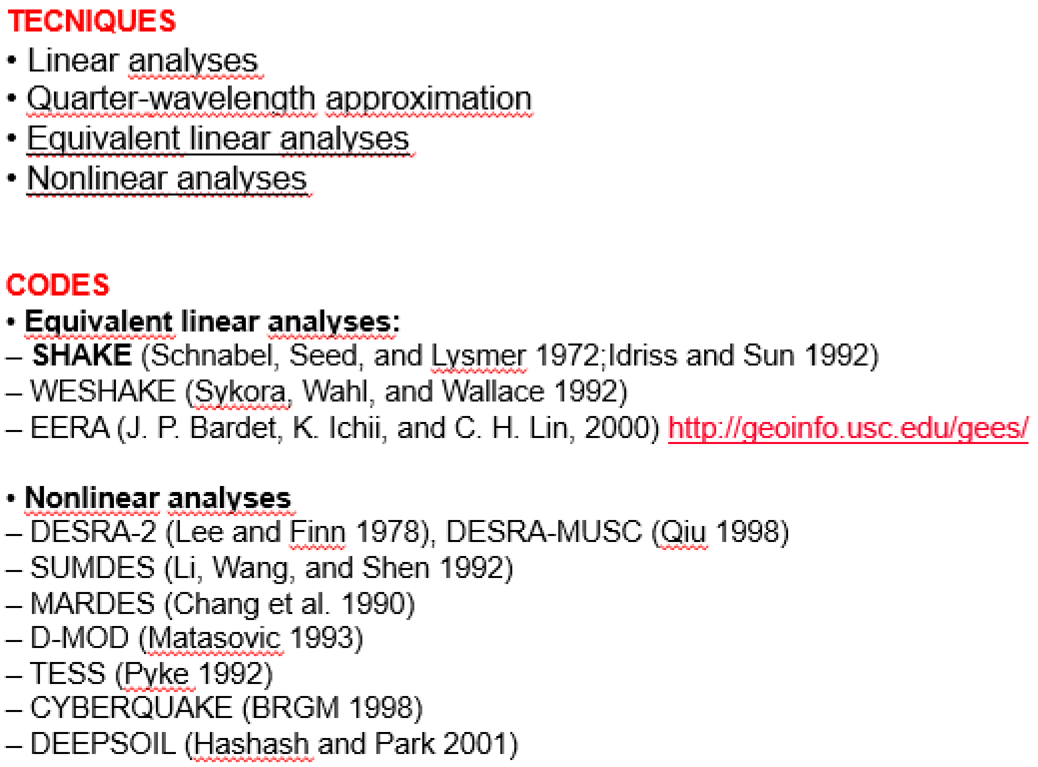
One dimensional response of soil columns

Two Steps:

- **(1) Input data**
  - Modeling the Soil profile
  - Input motion (earthquake record)
- **(2) Output results**
  - Acceleration, Velocity, Displacement time histories at the surface of the soil profile (common) or at various levels within the profile
  - Response spectra and Amplification
  - Max acceleration, strain and stress with depth

Assumptions:

- all boundaries are horizontal
- the response of a soil deposit is predominantly caused by SH-waves propagating vertically from the underlying bedrock
- the soil and bedrock surface are assumed to extend infinitely in the horizontal direction.



TECNIQUES

- Linear analyses
- Quarter-wavelength approximation
- Equivalent linear analyses
- Nonlinear analyses

CODES

- **Equivalent linear analyses:**

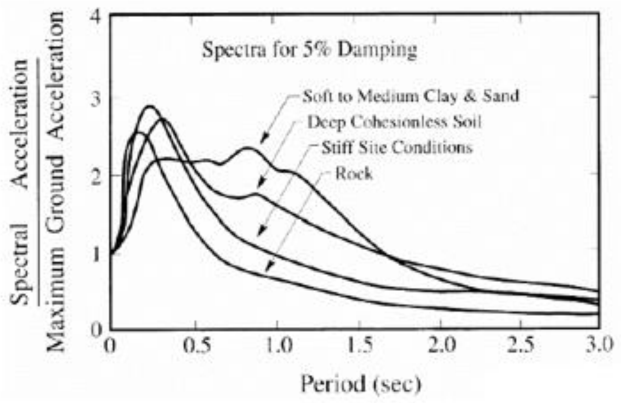
– **SHAKE** (Schnabel, Seed, and Lysmer 1972;Idriss and Sun 1992)
– WESHAKE (Sykora, Wahl, and Wallace 1992)
– EERA (J. P. Bardet, K. Ichii, and C. H. Lin, 2000) http://geoinfo.usc.edu/gees/

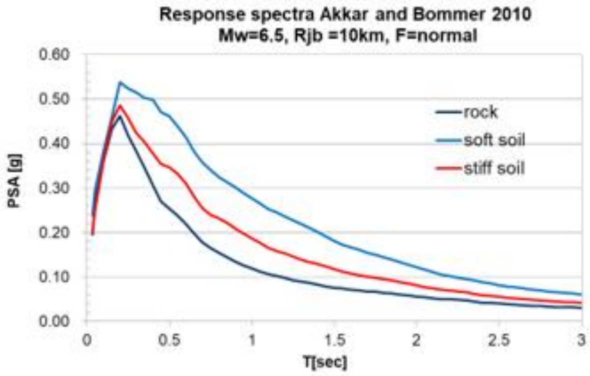
- **Nonlinear analyses**

– DESRA-2 (Lee and Finn 1978), DESRA-MUSC (Qiu 1998)
– SUMDES (Li, Wang, and Shen 1992)
– MARDES (Chang et al. 1990)
– D-MOD (Matasovic 1993)
– TESS (Pyke 1992)
– CYBERQUAKE (BRGM 1998)
– DEEPSOIL (Hashash and Park 2001)

Spectral amplification

Average normalized response spectra for 107 earthquake records grouped in four soil categories, *Seed et al. 1976*





Site effects and soil categorization: Vs30, EC8 European building code

According to Eurocode 8 , there are five typical ground types (A, B, C, D, E) that may be used to account for the influence of local ground conditions on the seismic action. The average shear wave velocity in the top 30 m from the surface is computed according to the following equation:

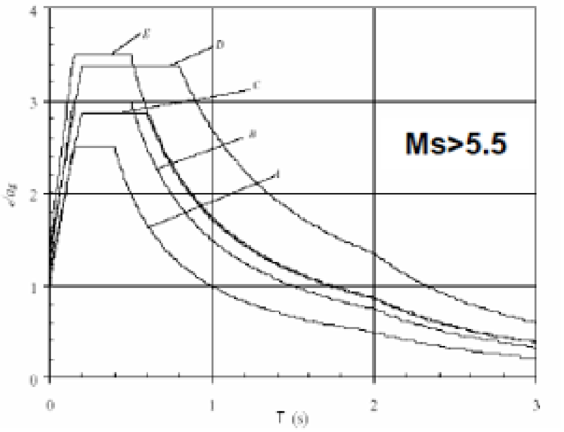
Shear wave velocity - upper 30m

$$V_{s,30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_i}}$$

h_i ,V_i thickness and velocity of i-layer up to 30m depth

EC8 European building code

Elastic Response Spectrum – Type 1



Parameters

Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0