Engineering Seismology and Seismic Hazard – 2019

Lecture 13

Measuring Ground Motion

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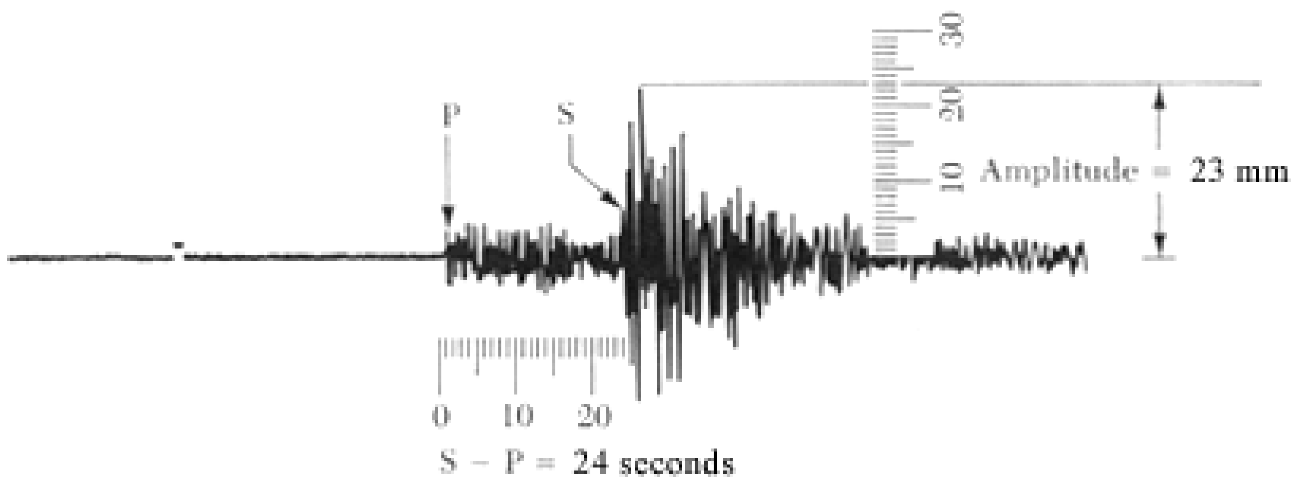
Measuring Ground Motion

A seismogram can be difficult to handle directly , therefore, for engineering purposes, it is often more convenient to use derived ground motion parameters such as: peak values (instantaneous), frequency content, duration, and various integral parameters.

Each of these emphasize a specific aspect of the earthquake phenomenon, and are thus used in different contexts.



Ground Motion Parameters

Instantaneous (peak) values:

PGA → peak ground acceleration (a_{max})

PGV → peak ground velocity (v_{max})

PGD → peak ground displacement (d_{max})

Integral parameters: they express the energy content of a signal and they are defined by the integration of a(t), v(t), d(t), times series, SA(T), SV(T).

Duration: defines the length of ground motion. There are different definitions of duration. It depends on magnitude and epicentral distance of the earthquake.

Frequency content: is represented by Fourier amplitude and phase spectrum and to some extent by the response spectrum.

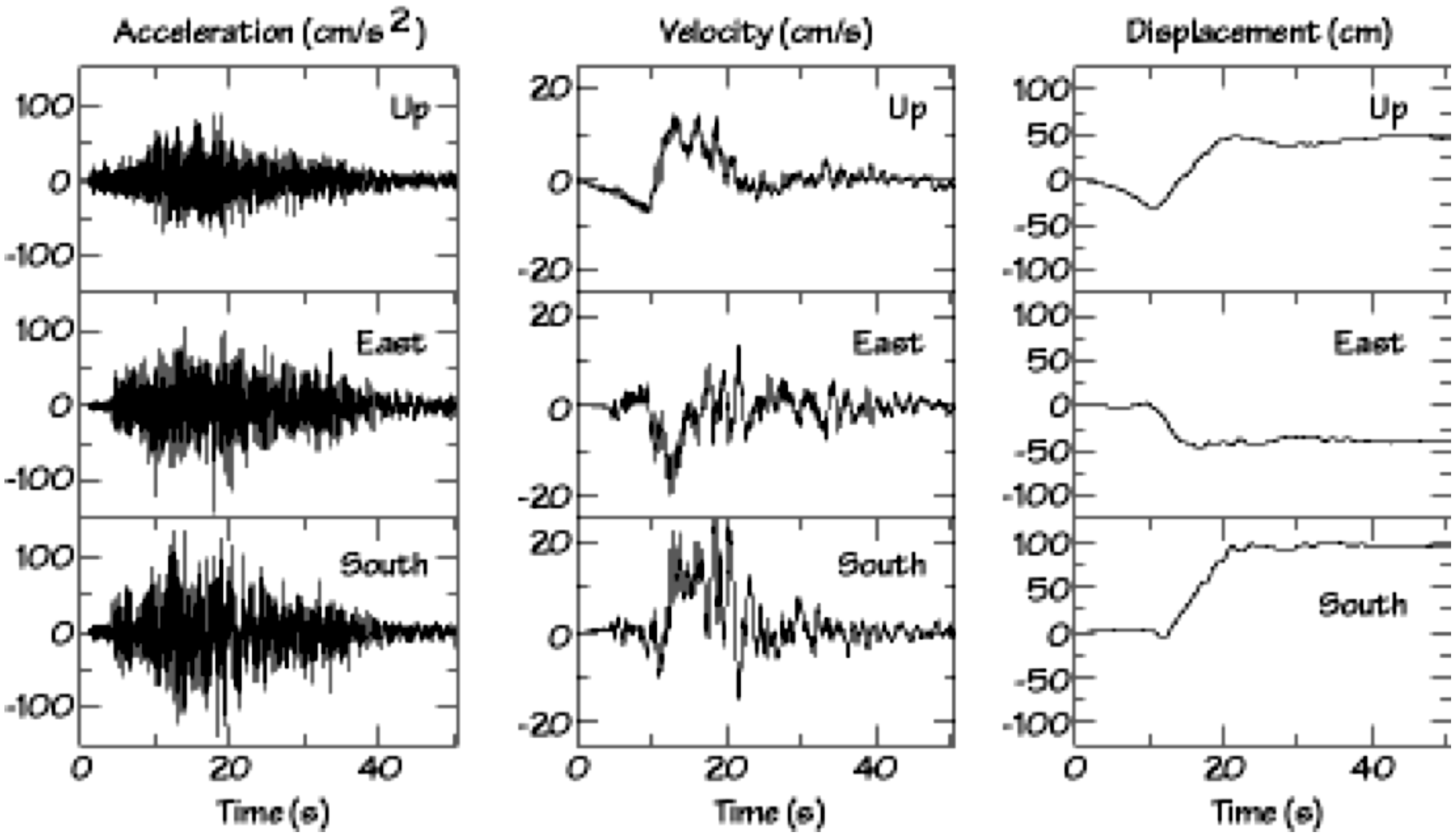
Ground Motion Parameters

PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
$I_a = \frac{\pi}{2g}\int [a(t)]^2 dt$	Arias Intensity
Sa (5%, 1.0Ts)	Spectral acceleration T = 1.0Ts (sliding mass)
Sa (5%, 1.5Ts)	Spectral acceleration T = 1.5Ts (sliding mass)
Sa (5%, 2.0Ts)	Spectral acceleration T = 2.0Ts (sliding mass)
$CAV = \int [a(t)] dt$	Cumulative Absolute Velocity
$I_c = a_{RMS}^{3/2}\sqrt{T_D}$	Characteristic Intensity
$VSI = \int_{0.1}^{2.5} S_v(5\%,T)dT$	Velocity Spectrum Intensity

Sv (5%, 1.0Ts)	Spectral velocity T = 1.0Ts (sliding mass)
Sv (5%, 1.5Ts)	Spectral velocity T = 1.5Ts (sliding mass)
Sv (5%, 2.0Ts)	Spectral velocity T = 2.0Ts (sliding mass)
$a_{RMS} = \sqrt{\frac{\int [a(t)]^2 dt}{T_D}}$	Root-Mean Square of acceleration
$v_{RMS} = \sqrt{\frac{\int [v(t)]^2 dt}{T_D}}$	Root-Mean Square of velocity
$ASI = \int_{0.1}^{0.5} S_a(5\%,T)dT$	Acceleration Spectrum Intensity
$D_{5\text{-}95}$	Significant duration
T_P	Pulse period
$T_m = \frac{\Sigma\left(\frac{C_i^2}{f_i}\right)}{\Sigma C_i^2}$	Mean period

A-V-D Time Histories

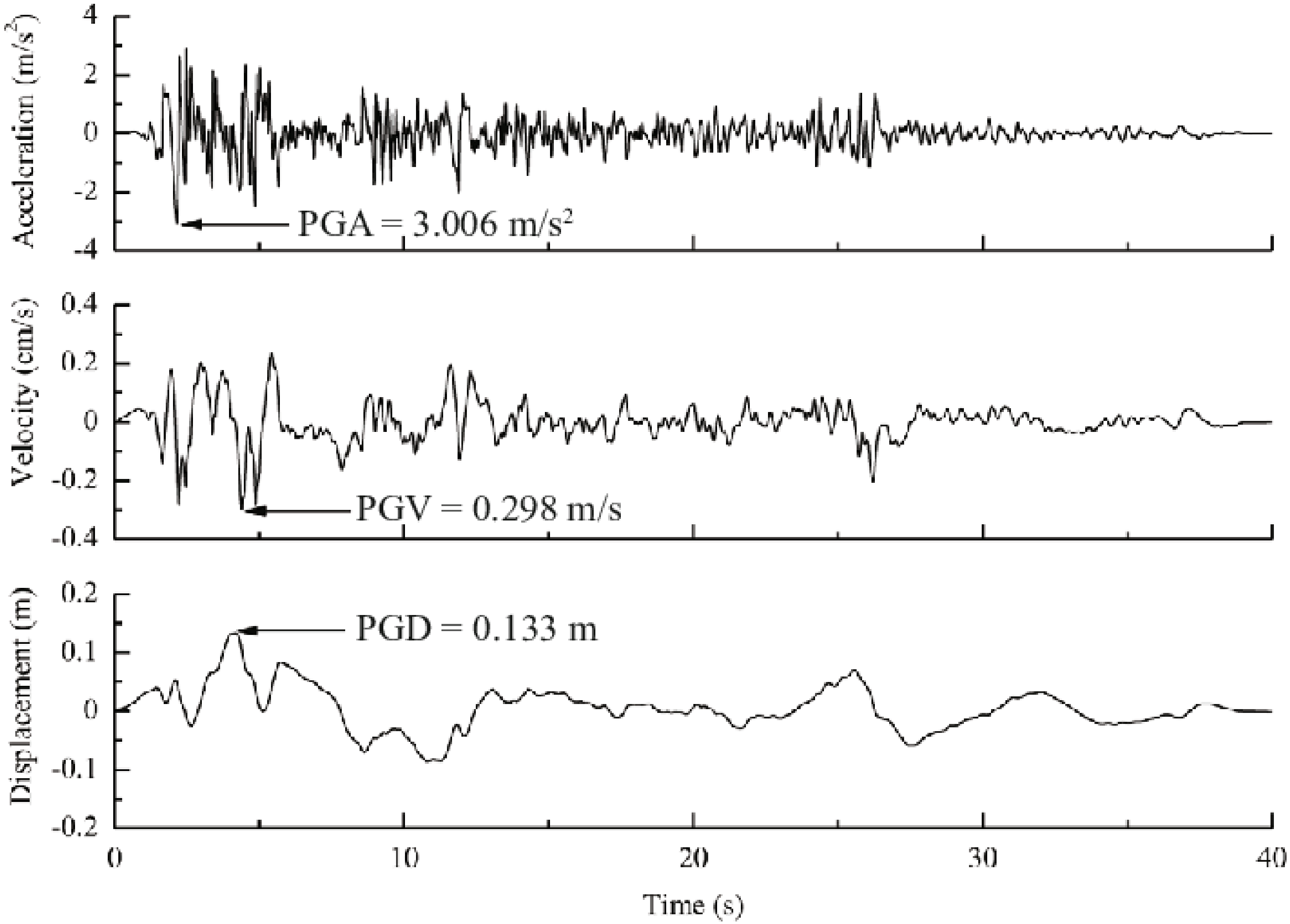
ACCELERATION, VELOCITY AND DISPLACEMENT



Integration

Differentiation

PGA – PGV – PGD



Acceleration (m/s²)
4
2
0
-2
-4
PGA = 3.006 m/s²
Velocity (cm/s)
0.4
0.2
0
-0.2
-0.4
PGV = 0.298 m/s
Displacement (m)
0.2
0.1
0
-0.1
-0.2
PGD = 0.133 m
0
10
20
30
40
Time (s)

Integral Parameters

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

→ RMS Acceleration:

Sensitive to the definition of the duration adopted

$$AI = \frac{\pi}{2g} \int_0^{T_d} [a(t)]^2 dt$$

→ Arias Intensity

It has units of velocities

$$CAV = \int_0^{T_d} |a(t)| dt$$

→ Cumulative Absolute Velocity

Defined for specific frequencies of engineering significance

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

→ Housner Intensity

Good correlation with damage potential

*NOTE: How Td is measured?

Duration

Duration of an earthquake is an important parameter since it influences the level of damage caused by a seismic event.

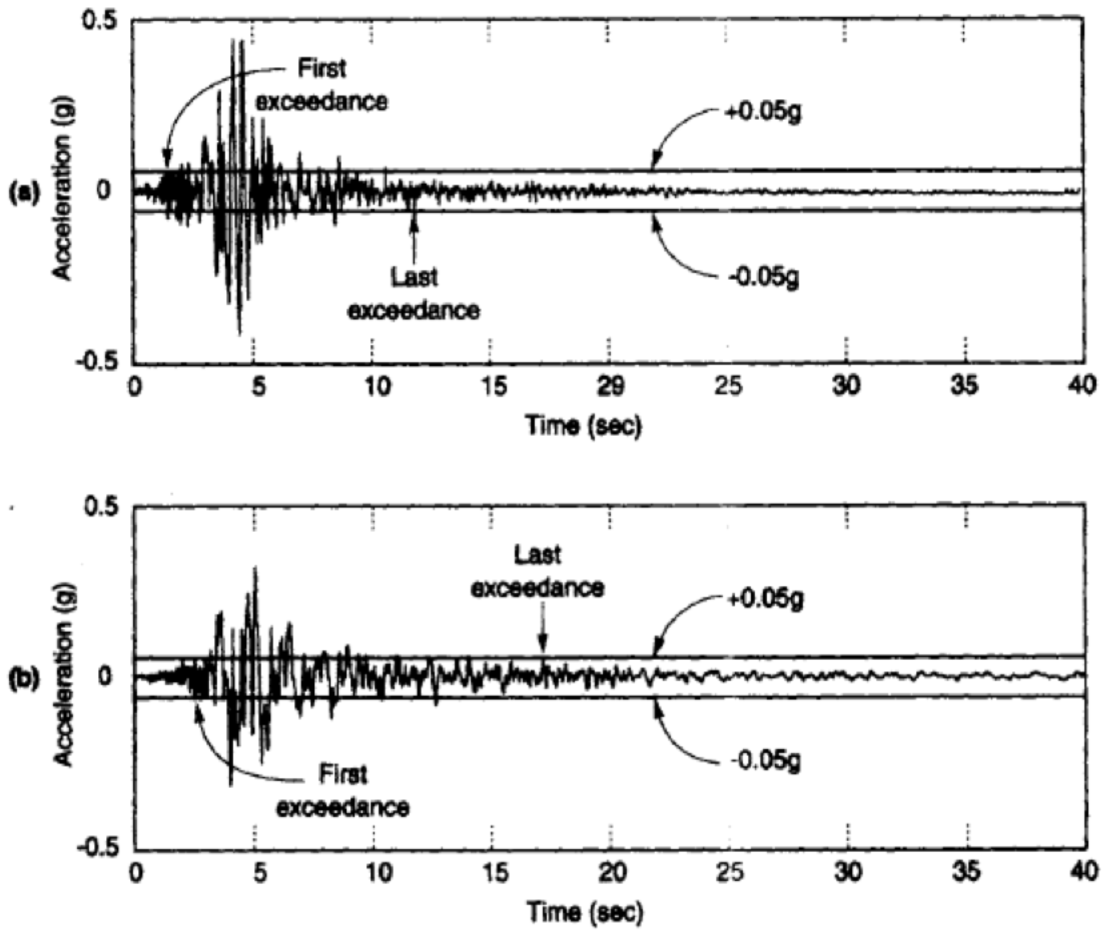
A shaking of high intensity but of short duration can cause less damage to a structure than a more moderate shaking characterized by a longer duration.

This is because long duration ground motion causes a greater number of loading cycles which affect the degradation of the stiffness of structures and the accumulation of pore water pressure in saturated, loose, sandy soil deposits (liquefaction).

The duration represents the time required for the release of the strain energy accumulated along a fault (but not only), therefore it increases with the magnitude of an earthquake.

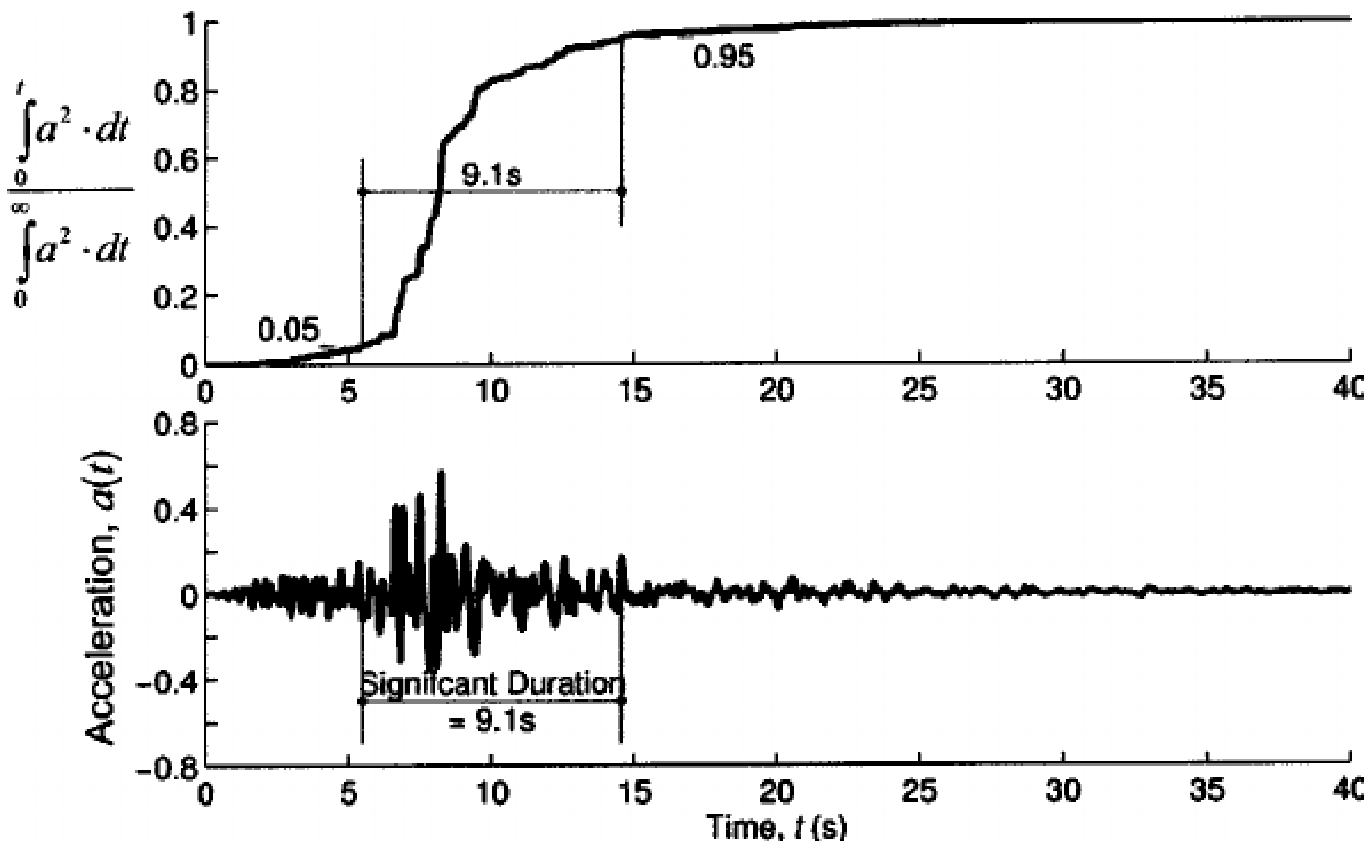
Bracketed Duration

Bracketed duration is the time between the <u>first and last exceedance</u> of specified threshold. Usually 0.05 g is chosen as threshold acceleration limit.



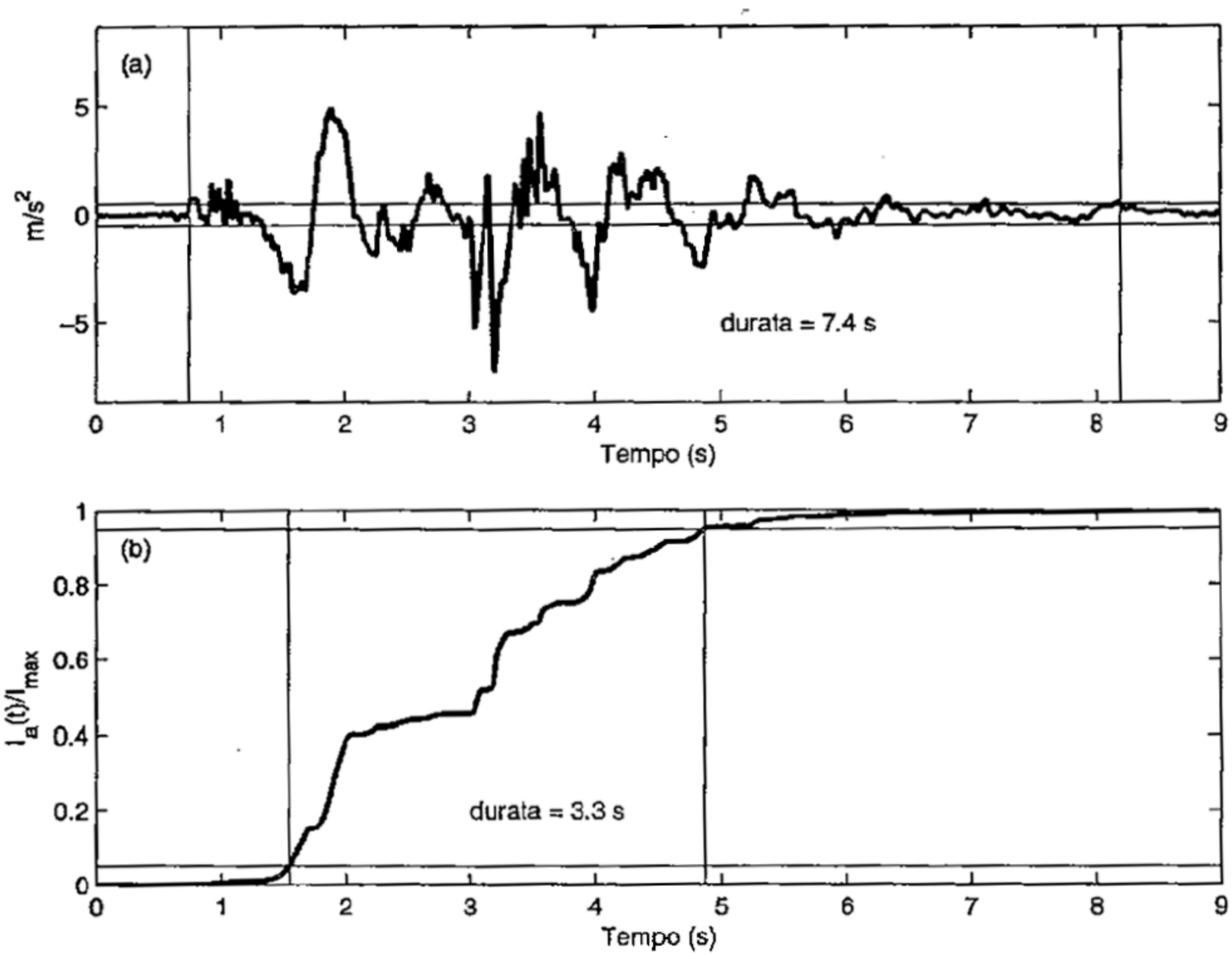
Significant Duration

T5–95 Significant duration time between 5% and 95% of energy release (from AI).
In few cases is computed between 5% and 75% (T5–75).



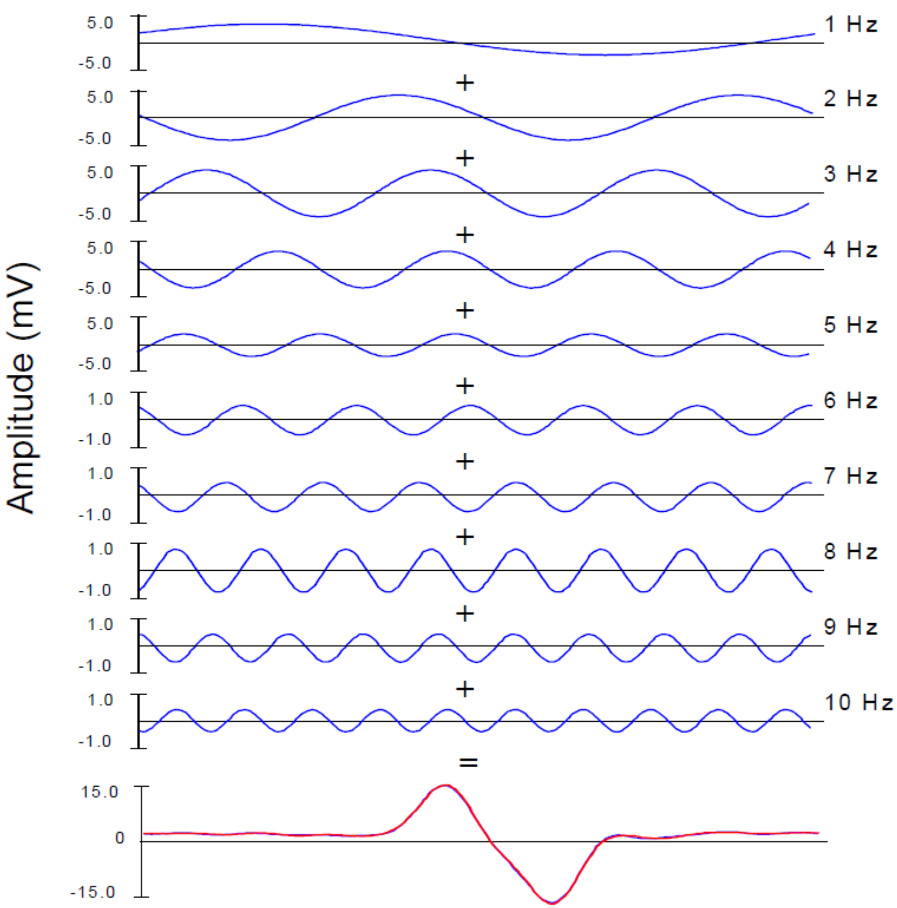
Comparing Duration Models

Be careful: depending on the calculation approach, duration estimates can be rather different → Uncertainty!

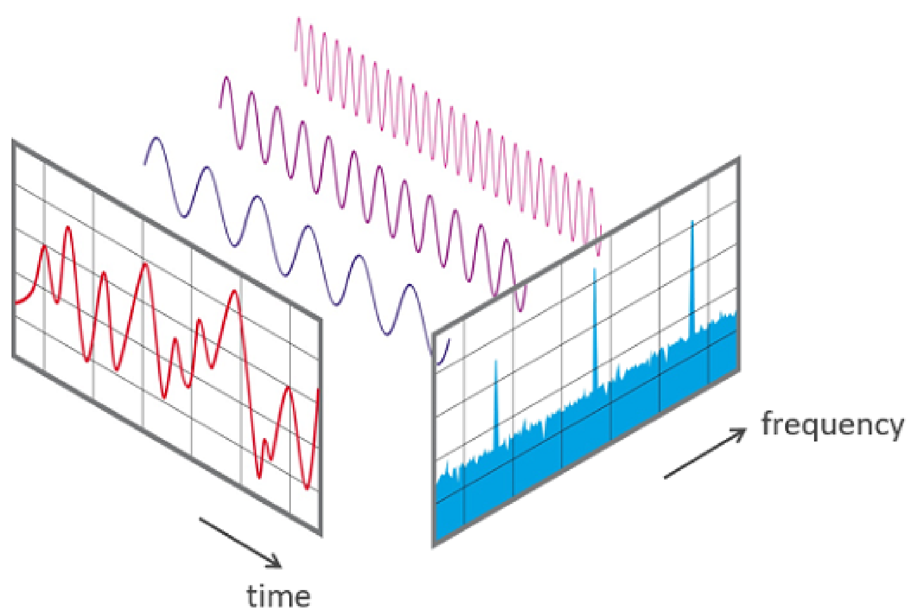


Fourier Spectrum

Any periodic function can be expanded in Fourier Series as a sum of infinite sinusoids with different amplitude (a), phase (ϕ) and frequency (ω):



$$x(t) = a_0 \sum_{n=1}^{\infty} a_n \sin(\omega_n t + \phi_n)$$



Fourier Spectrum

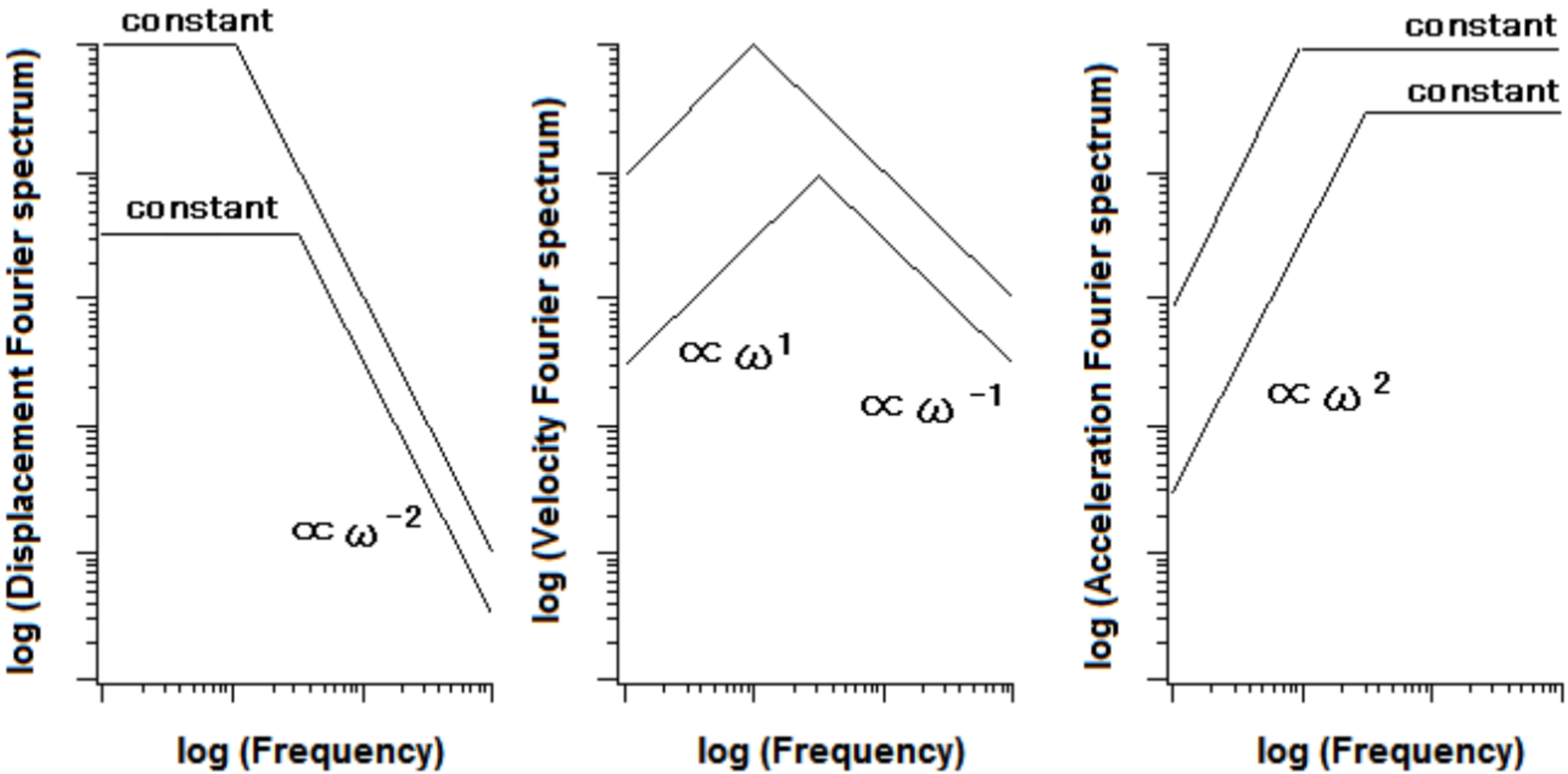
Fourier Amplitude Spectrum (FAS)

- It shows the variation of amplitude with frequency
- Illustrates how the amplitude of motion varies with frequency
- Expresses the frequency content of ground motion

Fourier Phase Spectrum

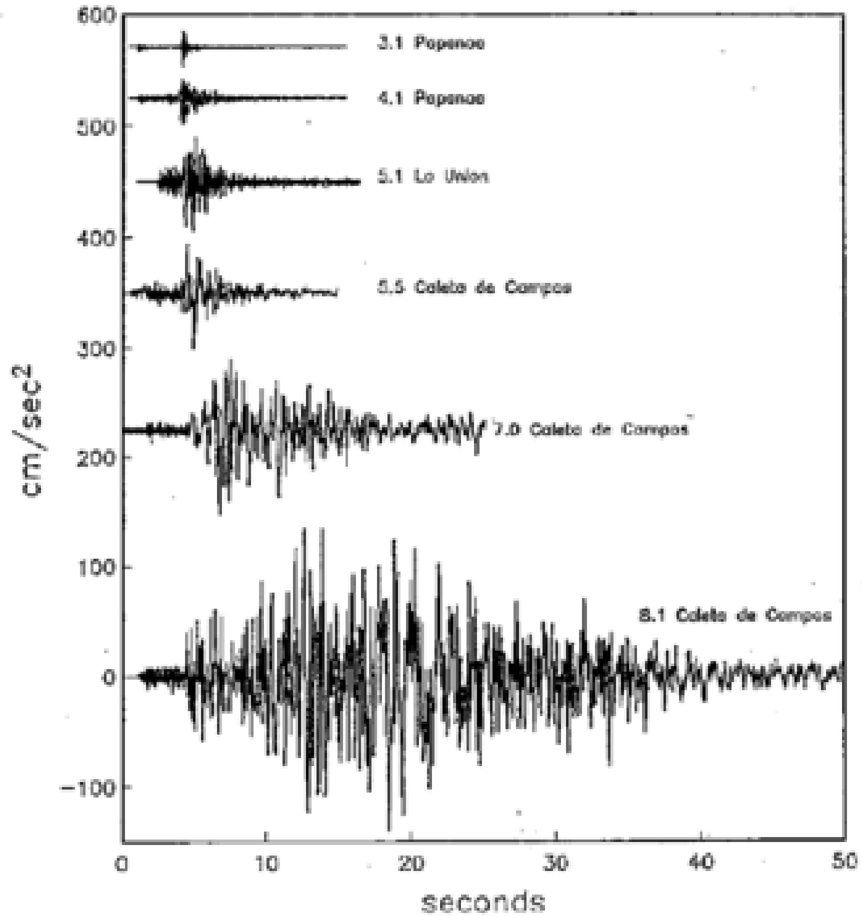
- It shows the variation of phase with frequency
- Phase angle controls time when the peaks of harmonic motion occur.
- Fourier phase spectrum is influenced by variation of ground motion with time

A-V-S Spectra

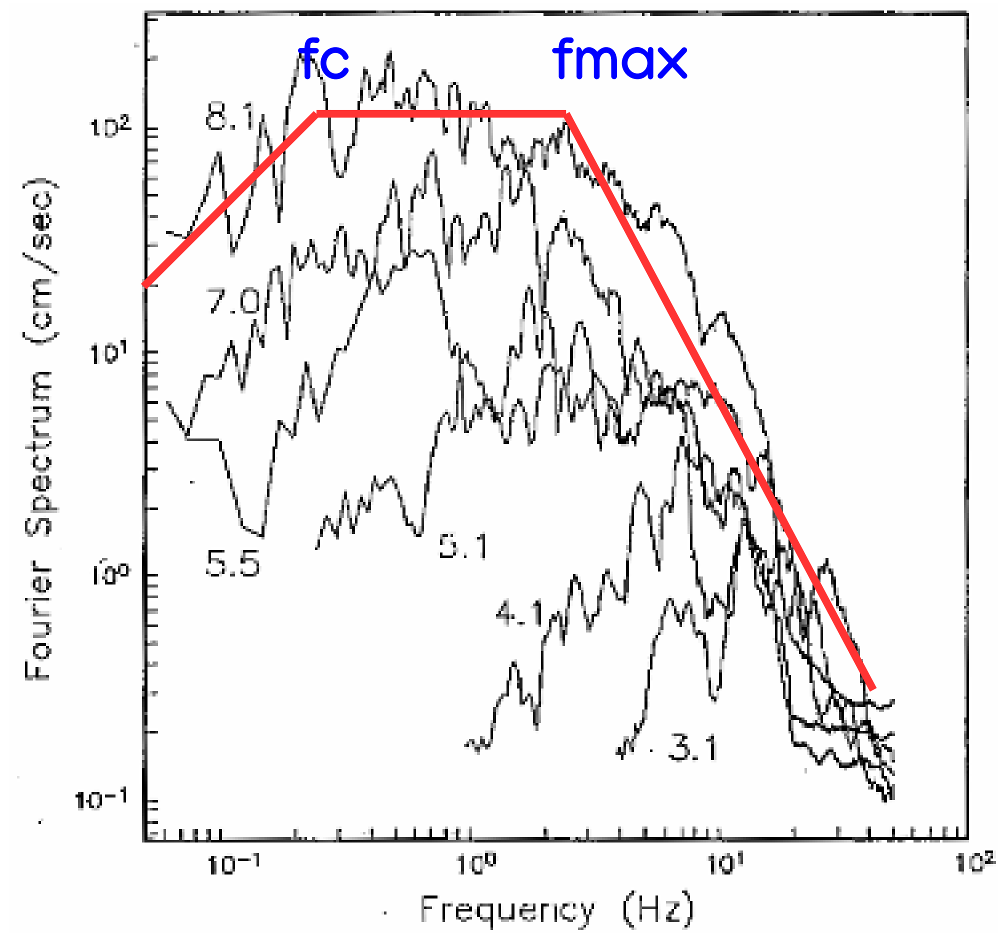

constant
constant
log (Displacement Fourier spectrum)
$\propto \omega^{-2}$
log (Frequency)
log (Velocity Fourier spectrum)
$\propto \omega^{1}$
$\propto \omega^{-1}$
log (Frequency)
constant
constant
log (Acceleration Fourier spectrum)
$\propto \omega^{2}$
log (Frequency)

Earthquake Spectrum

Acceleration Time Series

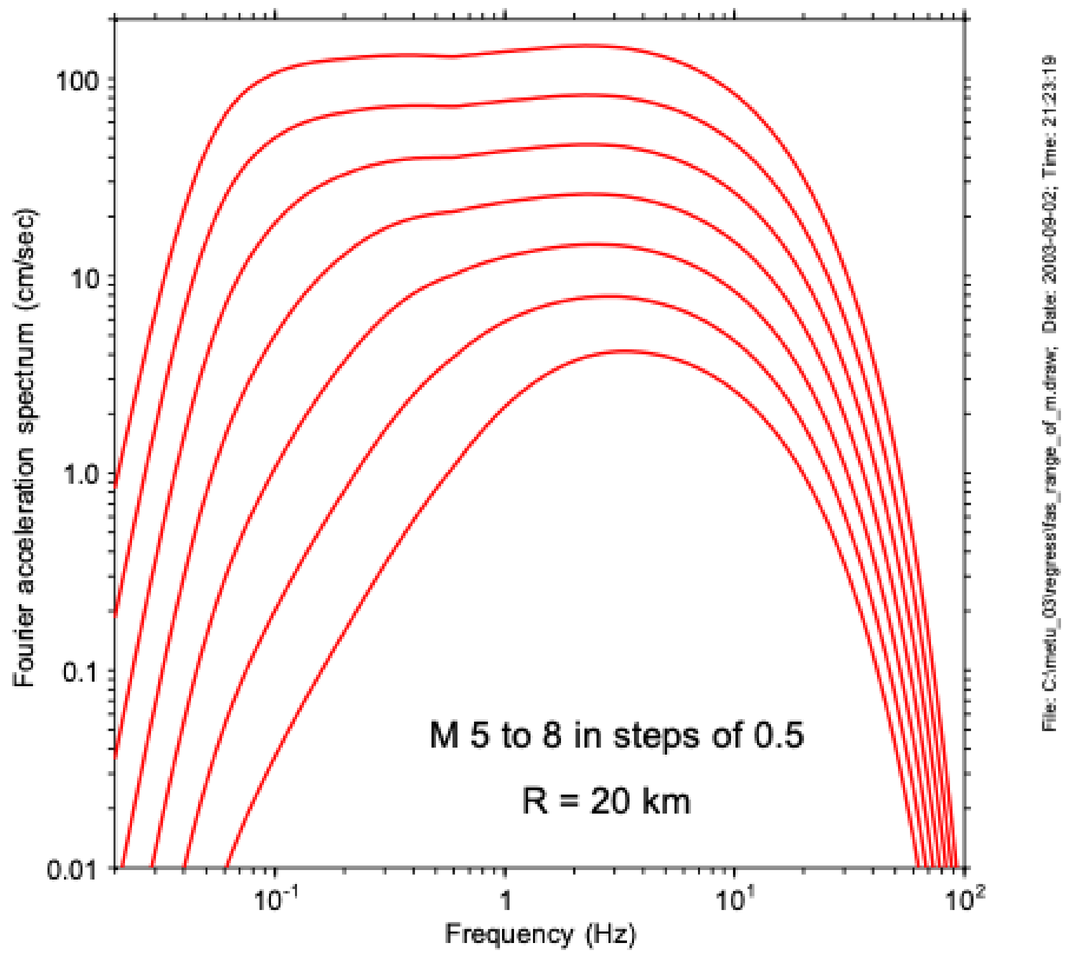


Fourier Amplitude Spectra



fc is inversely proportional to the cube root of seismic moment M0. Therefore, large earthquakes produce a seismic motion characterized by a higher energy content at low frequencies.

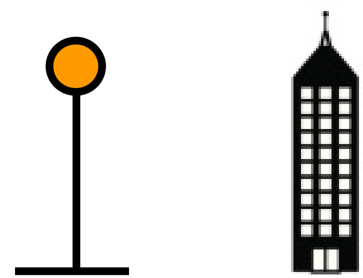
Earthquake Spectrum



The Harmonic Oscillator

For engineering purposes, it is often useful to represent ground motion as it would be experienced by a structure (building, bridges).

A convenient simplification is obtained by convolving the acceleration time-histories with the theoretical response of a damped one-dimensional harmonic oscillator (representing the structure).

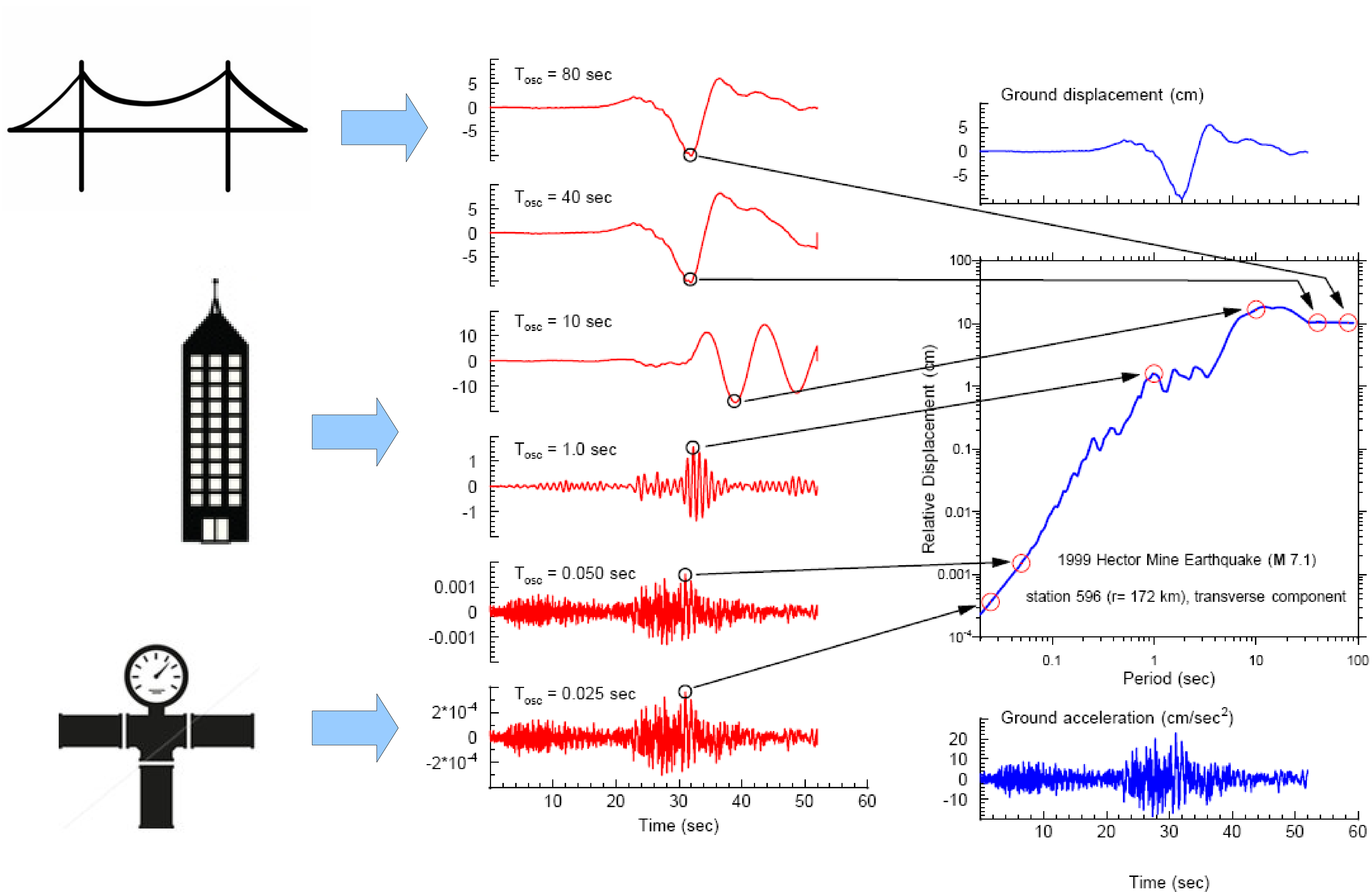


$$u(t) = -\frac{1}{\omega_d} \int_0^t \ddot{u}(\tau) e^{-\xi \omega_n (t-\tau)} \sin(\omega_d (t-\tau)) \, d\tau$$

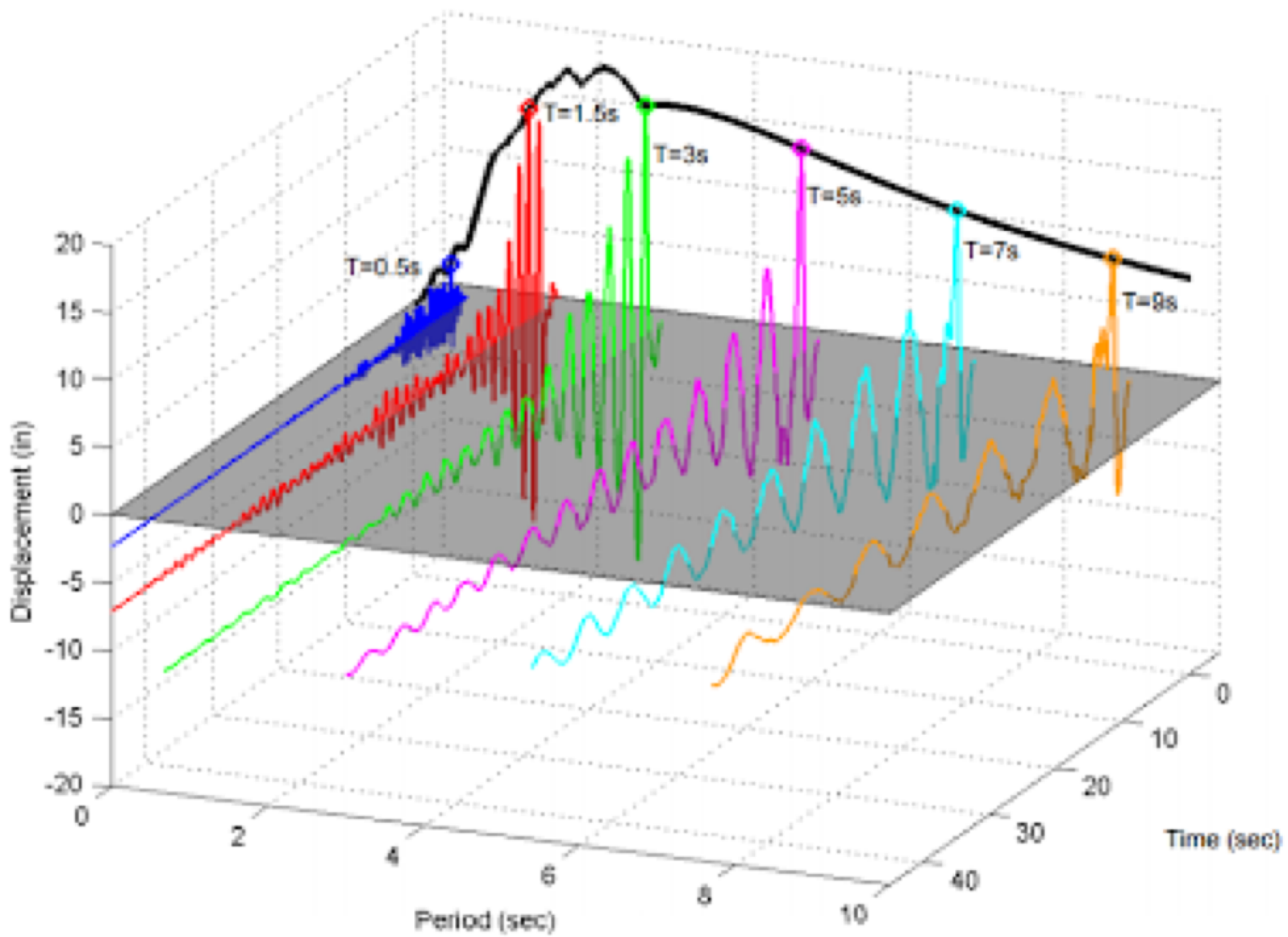
Duhamel's Integral

$$\omega_d = \omega_n \sqrt{1-\xi^2}$$

The Response Spectrum



The Response Spectrum



Velocity and Acceleration Spectra

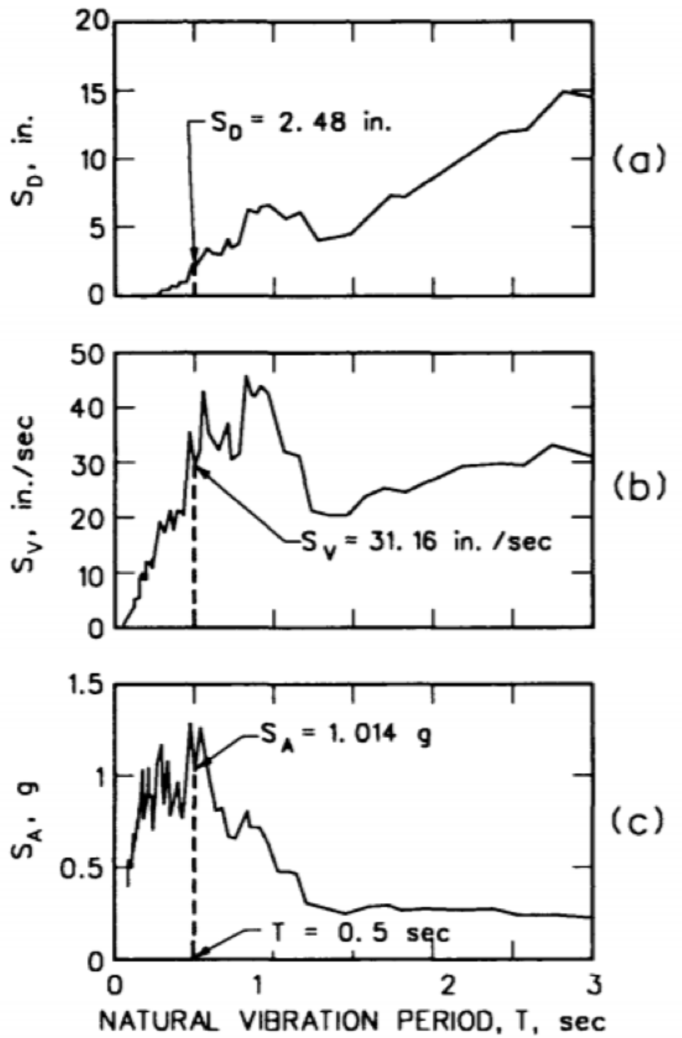


Figure 17. Displacement, pseudo-velocity pseudo-acceleration linear response spectra plots, β - 0.02, 1940 El Centro S00E component, from Chopra (1981)

Response spectra in velocity and acceleration can be obtained by derivation of the convolved signal (in displacement) before picking the maximum.

This procedure is however inefficient, as it requires to calculate derivatives for each vibration period.

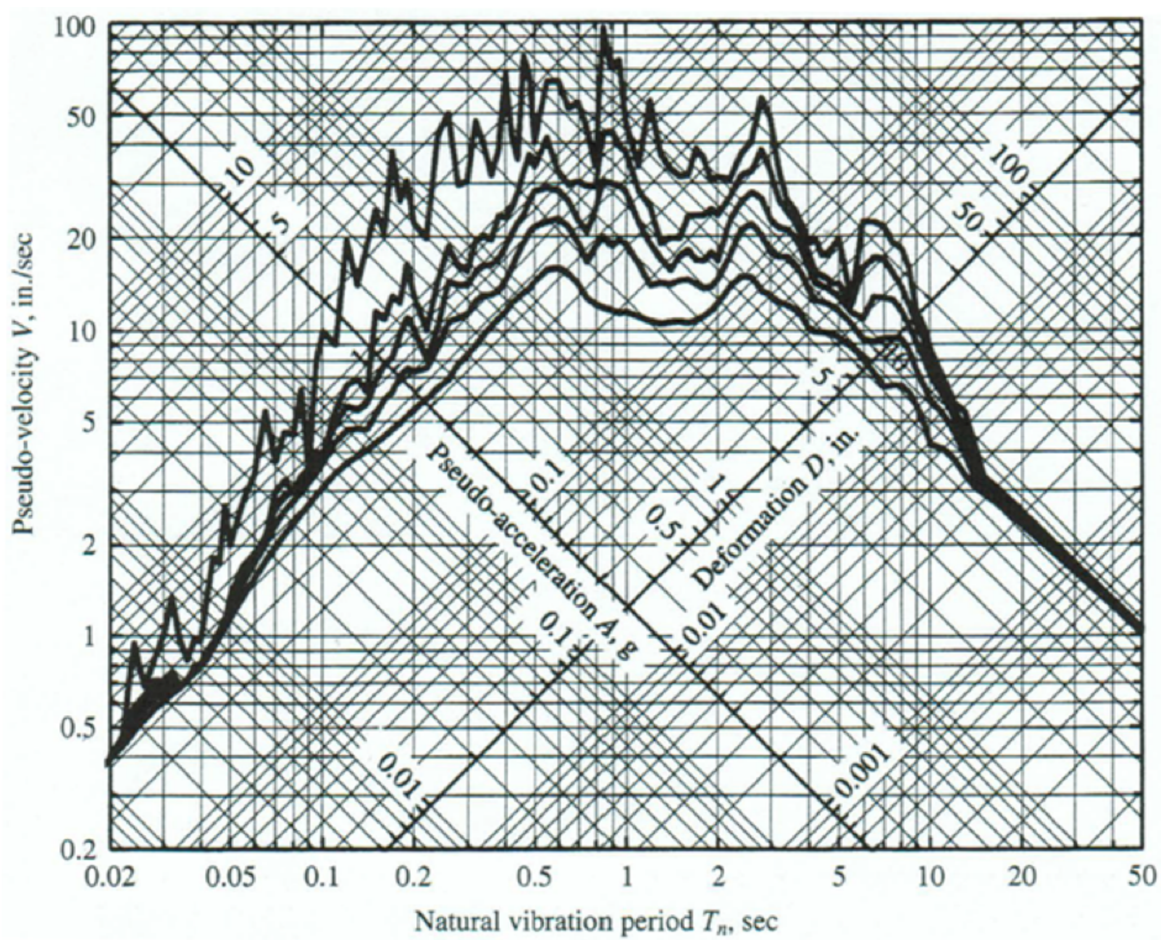
$$DRS = \max_t |u(t)|$$

$$VRS = \max_t |\dot{u}(t)|$$

$$ARS = \max_t |\ddot{u}(t)|$$

Pseudo Spectra

Pseudo spectra are a convenient simplification, as they can be simply obtained by multiplying the displacement response spectrum by the angular frequency.



$$PSV = \omega \, DRS$$

$$PSA = \omega^2 \, DRS$$

(from Chopra, 1995)

Relation with PGA, PGV, PGD