RESPONSE OF STRUCTURES (16)

I Main Topics

A Seismic records

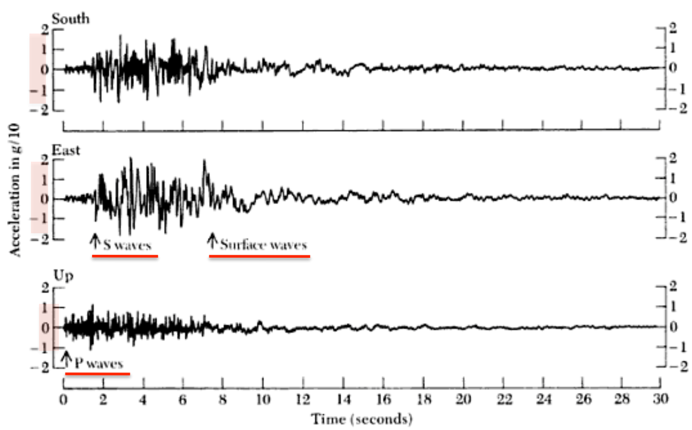
B Acceleration, velocity and displacement spectra

B Resonance and natural frequencies

C Response of structures

II Seismic time series records

A Accelerogram (plot of acceleration vs. time)



Three components of ground acceleration recorded from a site in Hollywood ~20 km from the 1971 San Fernando earthquake fault rupture. From Bolt, 1988.

B Time series records of acceleration, velocity, and displacement

1 Acceleration (a)
- a $a = dv/dt$
- b Peak <u>force</u> at peak acceleration
- c Peak acceleration at right: ~1100cm/sec^2
- d Time of peak acceleration: ~7.5 sec

2 Velocity (speed) (v)
- a $v = du/dt$
- b Peak <u>kinetic energy</u> at peak velocity
- c Peak velocity at right: ~115 cm/sec
- d Time of peak velocity: ~3 sec

3 Displacement (u)
- a Peak displacement at right: ~40 cm
- b Time of peak displacement: ~ 5 sec

Recordings of N. 14° E. component of horizontal ground motion at Pacoima damsite for 1971 San Fernando earthquake (from Page and others, 1975).

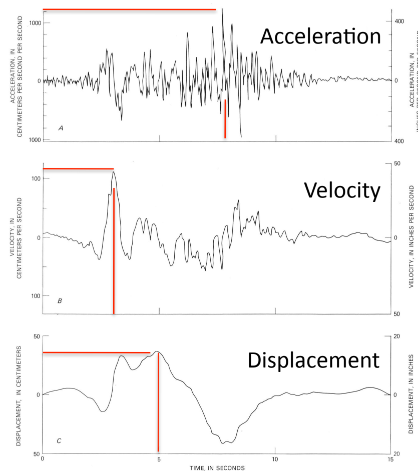


Fig. 31 from USGS Prof. Paper 1360

III Seismic spectra

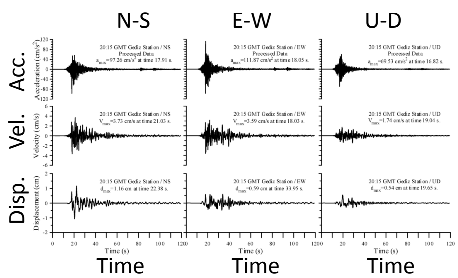
A Spectra represent parameters (e.g., displacement, velocity, and acceleration) as a function of wave frequency (or period), not time

B Reveal the frequency (or period) and amplitude of the most energetic/forceful waves

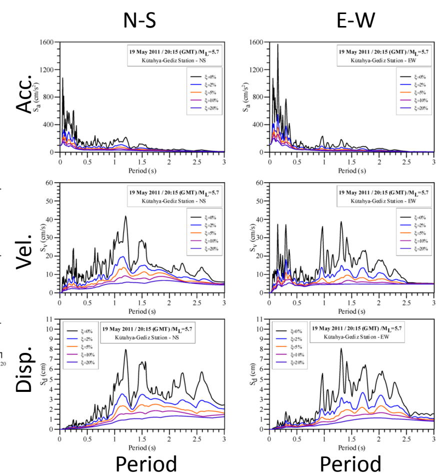
III Seismic Spectra

C Example: Simav earthquake, Turkey, 2011, M = 5.7-5.9

Time series records



Seismic spectra for Simav event

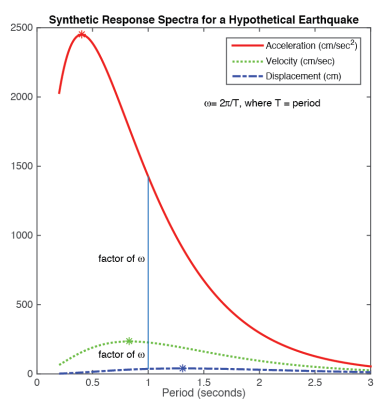


Doğangün et al., Buildings 2013, 3, 173-190; doi:10.3390/buildings3010173
http://www.mdpi.com/2075-5309/3/1/173/htm

III Seismic Spectra

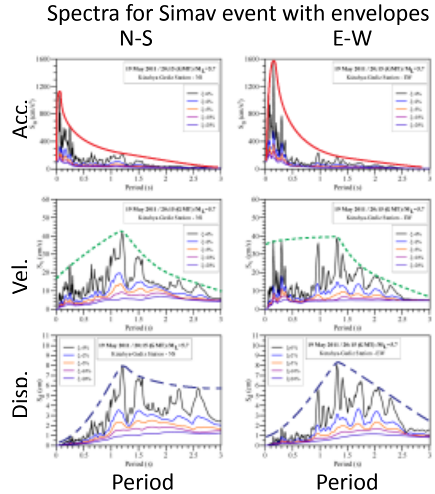
D Seismic spectra envelopes

Example: Simav earthquake, Turkey, 2011, M = 5.7-5.9



Envelopes give maximum amplitudes

Spectra for Simav event with envelopes



Doğangün et al., Buildings 2013, 3, 173-190; doi:10.3390/buildings3010173
http://www.mdpi.com/2075-5309/3/1/173/htm

III Seismic spectra

E Relationships among spectral envelopes

1 $y = A\sin\left[(2\pi/\lambda)(x+vt)\right]$

$v = \lambda/T = f\lambda;\ \lambda = v/f$

$y = A\sin\left[(2\pi f/v)(x+vt)\right]$

2 Now consider a particular point

$y_0 = y(x=0)$

$= A\sin\left[(2\pi f/v)(vt)\right]$

$= A\sin(2\pi ft)$

3 *Let* $\omega = 2\pi f = 2\pi/T =$ *angular frequency*

$y_0 = A\sin(\omega t)$

$y_0' = \frac{d\left[A\sin(\omega t)\right]}{dt} = A\omega\cos(\omega t)$

$y_0'' = \frac{d(y_0')}{dt} = \frac{d\left[A\omega\cos(\omega t)\right]}{dt} = -A\omega^2\sin(\omega t) = -\omega^2 y_0$

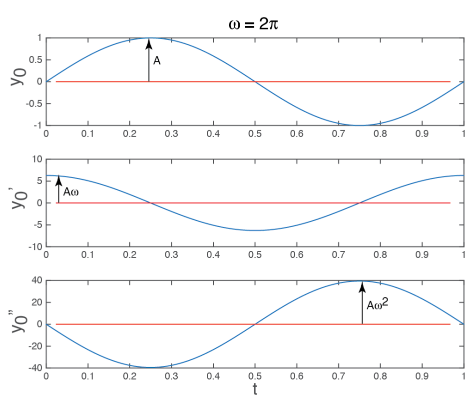
$\omega = \left(\left|\frac{y_0''}{y_0}\right|\right)^{1/2}$

III Seismic spectra

F Amplitude relationships among displacement, velocity, and accelerations for a single angular frequency

Let $\omega = 2\pi f = 2\pi/T =$ *angular frequency*

$y_0 = A\sin(\omega t)$ $y_0' = A\omega\cos(\omega t)$ $y_0'' = -A\omega^2\sin(\omega t) = -\omega^2 y_0$

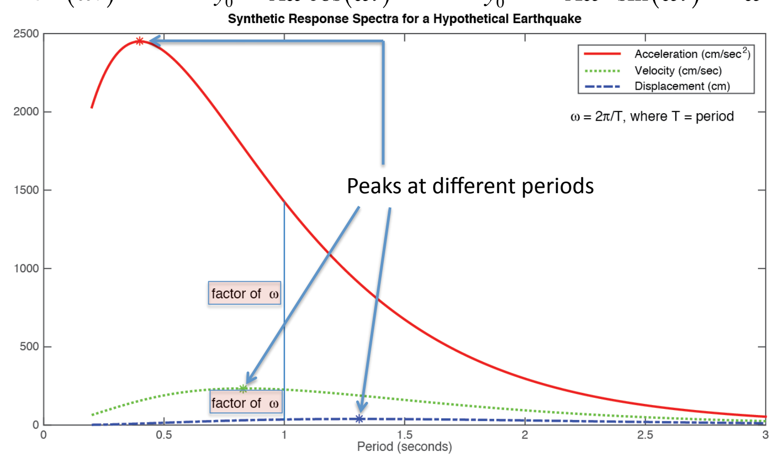


III Seismic spectra

F Relationships among spectral envelopes for a frequency range

Let $\omega = 2\pi f = 2\pi/T = \text{angular frequency}$

$y_0 = A\sin(\omega t)$ $\quad y_0' = A\omega\cos(\omega t)$ $\quad y_0'' = -A\omega^2\sin(\omega t) = -\omega^2 y_0$



III Seismic spectra

Frequency (f) (Hz)	0.01*	0.1*	1*	10*	100
Angular frequency ω	0.06	0.6	6	63	628
Maximum displacement (y) (m)	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Maximum velocity y' (= ω y) (m/sec)	6×10^{-5}	6×10^{-4}	6×10^{-3}	6×10^{-2}	6×10^{-1}
Max. acceleration y" (= |-ω² y|) (m/sec²)	39×10^{-5}	39×10^{-4}	39×10^{-3}	39×10^{-2}	39×10^{-1}

G Max. acceleration (forces) commonly at 2-10 Hz (T=0.1-0.5 sec), max. velocities (kinetic energy) at 0.5-2 Hz (T=0.5-2 sec), and max. displacements at 0.006-0.5 Hz (T=2-160 sec)

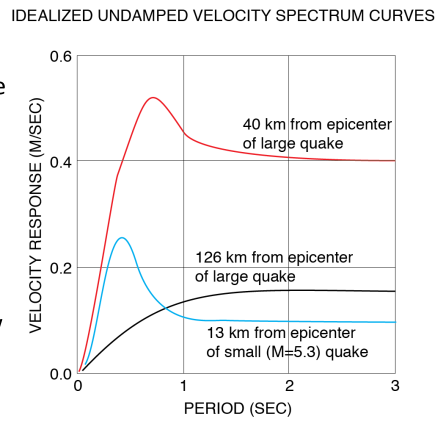
1. High frequency (small period) waves: high amplitudes of acceleration, small amplitudes of displacement
2. Low frequency (long period) waves: low amplitudes of acceleration, large amplitudes of displacement

*Important frequency for design of large engineering structures

III Seismic spectra

H Effects of source and distance

1. A small, nearby earthquake can affect short-period structures more than a larger, distant quake
2. A large, distant earthquake can affect long-period structures more than a smaller, nearby quake
3. Short-period (high frequency) waves attenuate with distance more readily than long-period (low frequency) waves



From Housner, 1970, in Wiegel, 1970

IV Resonance and natural frequencies

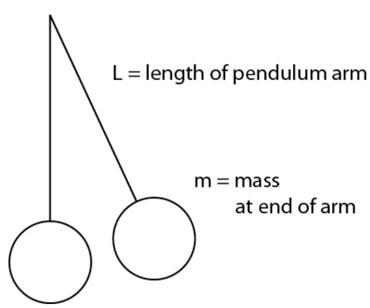
A Resonance: vibration of large amplitude due to arrival of energy at a particular frequency

B Natural frequency: The frequency at which a structure will resonate

C Natural frequency of a pendulum

1. Natural period: $T = 2\pi(L/g)^{1/2}$
   Natural period increases with length
2. Natural frequency: $f = 1/T = (g/L)^{1/2}/(2\pi)$
3. Natural angular frequency: $\omega = 2\pi f = (g/L)^{1/2}$

Diagram of a simple pendulum



IV Resonance and natural frequencies

D Natural frequency of a mass on a spring (simple harmonic oscillator)

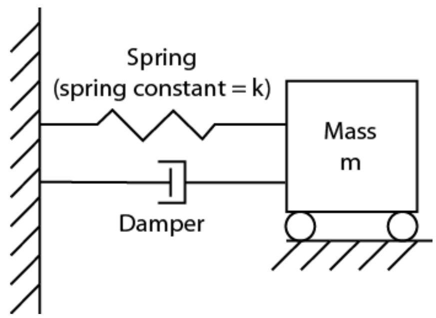
1 Natural period: $T = 2\pi(m/k)^{1/2}$

2 Natural frequency: $f = 1/T = (k/m)^{1/2}/(2\pi)$

3 Natural angular frequency: $\omega = 2\pi f = (k/m)^{1/2}$

* No damping in these expressions

Diagram of a simple harmonic oscillator with damping

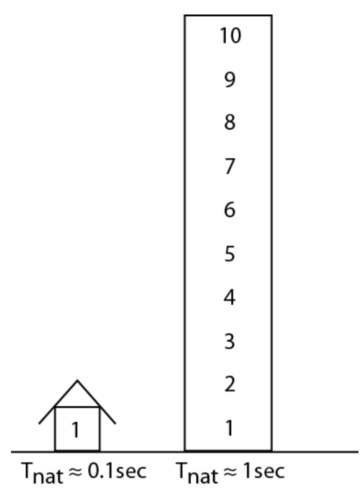


IV Resonance and natural frequencies

E Rule of thumb for buildings: natural period = # of stories/10

F Avoid structural designs with natural periods that match the natural period of the underlying materials (or the source)

G Previous experience helpful for step F



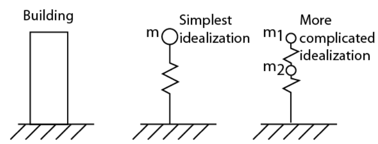
V Response of structures

A Earthquakes commonly impart large shear forces at the base of a building

B Bolt buildings to foundations and have sufficiently stiff ground floors

C Asymmetric designs susceptible to twisting

D Sophisticated models are used now to help design critical structures (beyond the scope of this course)



Collapsed General Hospital
1985 Mexico City earthquake

http://en.wikipedia.org/wiki/1985_Mexico_City_earthquake