CHARACTERIZATION OF GROUND RESPONSE TO SHAKING (15)

I Main Topics (see USGS Professional Paper 1360
- A Ground Response "Equations"
- B Linear response of ground
- C Frequency-dependent effects
- D Use of shear wave velocity as a predictor of shaking

II Ground response = f(source strength, path, "receiver")
- A Empirical equation of Joyner and Boore (PP 1360: p. 204)

$$\log y = c_0 + c_1(\mathbf{M}_W - 6) + c_2(\mathbf{M}_W - 6)^2 + c_3 \log r + c_4 r + S$$

· y = ground-motion parameter

· c_x = frequency-dependent constants

· $\mathbf{M}_W$ = Moment magnitude

· $r = \sqrt{(d^2 + h^2)}$: d = dist. from surface trace of fault; h = pseudodepth.

· S = 0 (rock sites); $S = C_m \log (V_{shear}/V_0)$ (soil sites)

- B Evernden's ground-motion equations (PP 1360: p. 201)
- C Arias Intensity (acceleration) equation (PP 1360: p. 331-333)

$$\text{Log } I_a = K_o + K_m\mathbf{M}_W - 2 \log r + K_\sigma P$$

· I_a = Arias intensity (dimensions of acceleration)

http://www.itc.nl/ilwis/Applications/Earth_Sciences/App07.html

· K_o and K_m **=** constants

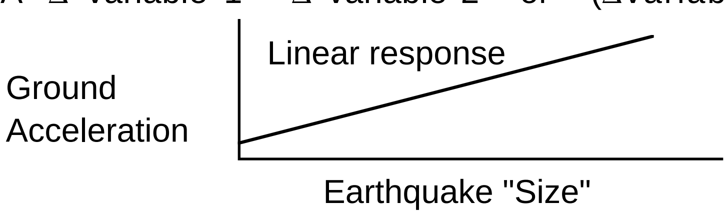
· $\mathbf{M}_W$ = Moment magnitude

· r = distance from slip surface

• $K_\sigma P$ = probability terms (This accounts for path [geology] effects)

See also http://rccg03.usc.edu/Software/EERA/EERA_Manual.pdf

III Linear behavior
- A Δ variable 1 ~ Δ variable 2 or (Δvariable1)/(Δvariable2) = constant



<u>The response to a small stimulus can be easily and accurately scaled up (⇒) to predict the response to a large stimulus for linear cases.</u>

- B Ground response to explosions ⇒ response to seismic waves

(Even though strains from blasts are two orders of magnitude or so less than for earthquakes)

C Ground response to little quakes ⇒ ground response to large quakes

D Linear response <u>not adequate</u> to treat liquefaction phenomena; the near-epicenter response to large quakes is nonlinear.

IV Frequency-dependent effects

A Fourier analysis: If a quantity (e.g. acceleration, velocity, displacement) is a function of time, then the same information can be portrayed as a function of frequency

B Examples from LA (Prof Paper 1360, p. 227-228)

1 T < 0.5 seconds: Shaking on Quaternary sedimentary deposits is 3-4 times that of sites founded on crystalline rock.

2 T > 0.5 seconds: Ground motion increases as thickness of Quaternary deposits increases and/or as depth to basement rock increases

a Ground motion depends on $\mu_{\text{"ave"}}$ ("average" shear modulus)

b $\mu_{\text{Quaternary deposits}} < \mu_{\text{Basement rocks}}$

3 Depth over which the sediment thickness is important scales with the wave period and therefore the wavelength (longer wavelength waves stimulate material at greater depths).

4 Sites with thin alluvium amplify shaking over a narrower frequency range than sites with thick alluvium.

V Use of shear wave velocity (V_S) for predicting ground response

A Shear strain = Shear Stress/Shear modulus $\gamma = \tau_s/\mu$

For a given stress, <u>the material with a lower μ deforms more</u>

B $V_s = (\mu/\rho)^{1/2}$ (ρ = density)

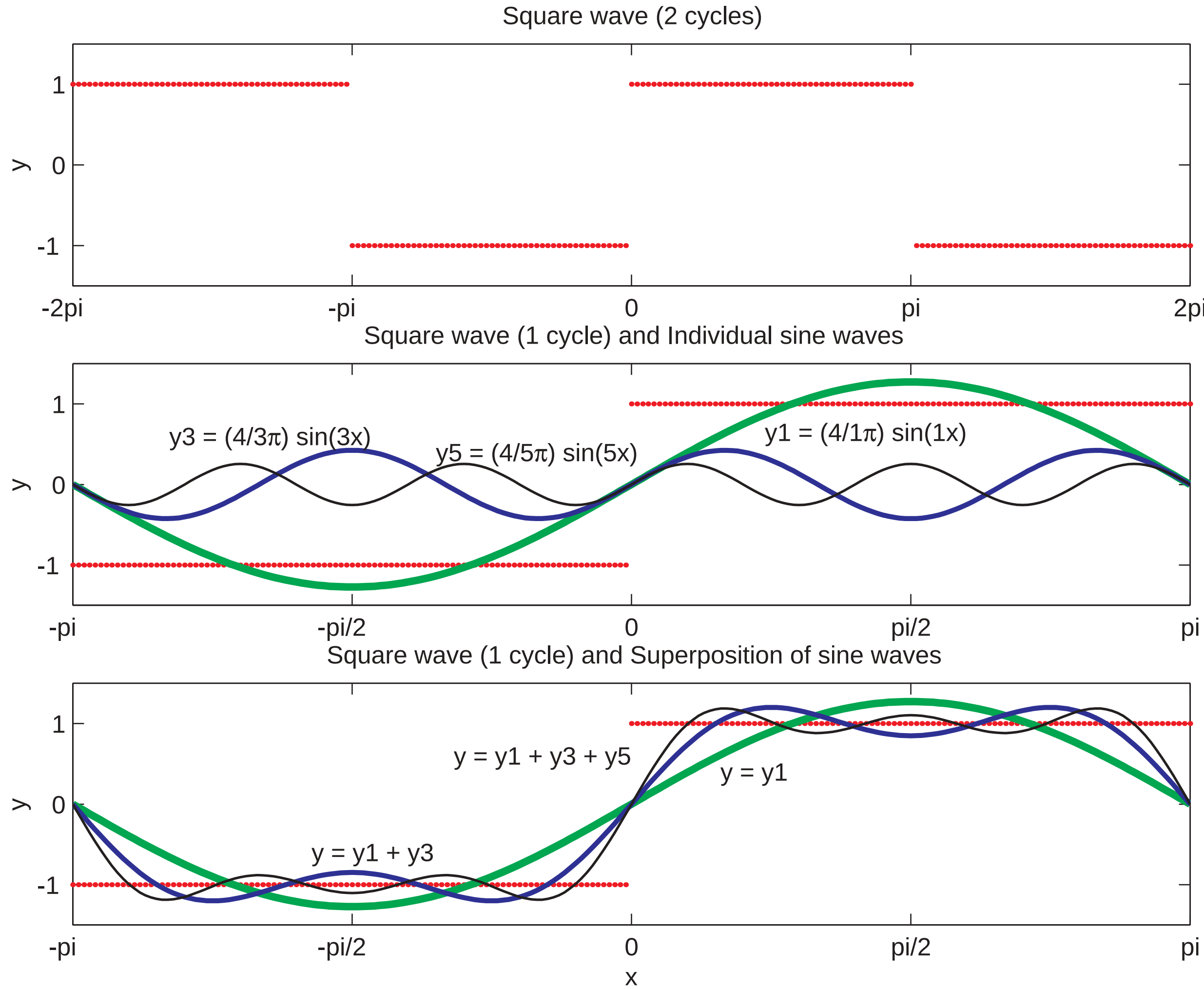
C <u>Low V_S</u> ⇒ <u>low μ</u> (i.e. a higher deformability

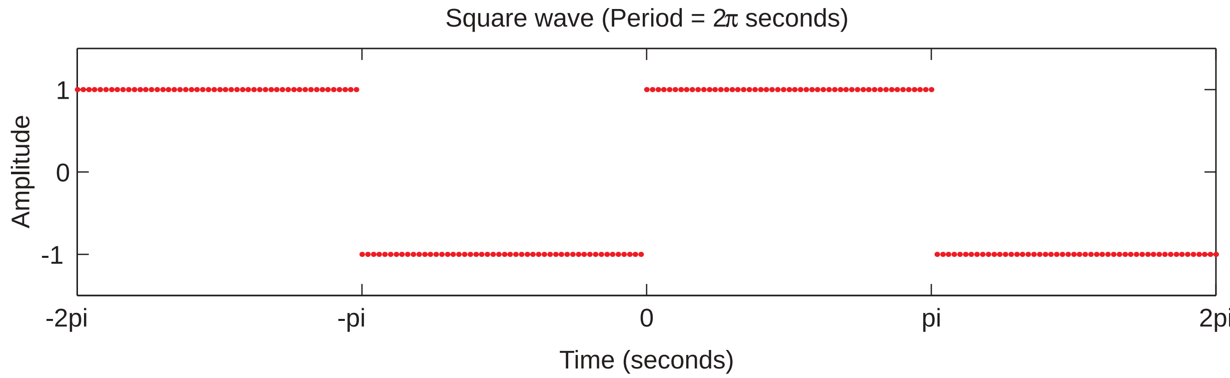
D S-wave amplitude ~ $(\cos\theta_i)^{1/2}/(\rho V_s)^{1/2}$, where θ_i is the angle of incidence as measured from the vertical

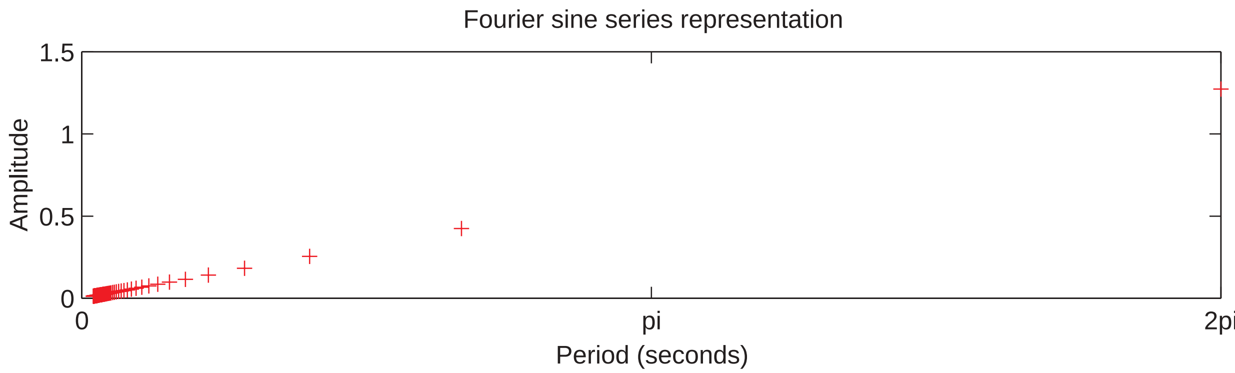
E S-wave amplitude ~ $\dfrac{1}{(\rho V_s)^{1/2}} = \dfrac{1}{\rho^{1/2}\left[(\mu/\rho)^{1/2}\right]^{1/2}} = \dfrac{1}{\rho^{1/2}\left[(\mu/\rho)^{1/4}\right]} = \dfrac{1}{(\mu\rho)^{1/4}}$

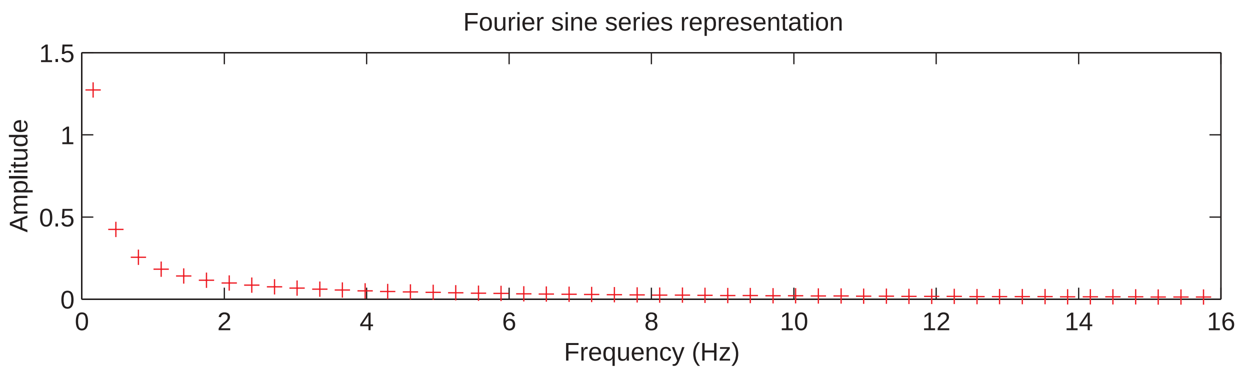
Decreases in V_S, μ, or ρ ⇒ increases in S-wave amplitude

F <u>S-wave velocities can be used to predict the relative shaking at different sites</u>.


Square wave (2 cycles)
y
1
0
-1
-2pi
-pi
0
pi
2pi
Square wave (1 cycle) and Individual sine waves
y3 = (4/3π) sin(3x)
y5 = (4/5π) sin(5x)
y1 = (4/1π) sin(1x)
-pi
-pi/2
pi/2
Square wave (1 cycle) and Superposition of sine waves
y = y1 + y3 + y5
y = y1
y = y1 + y3
x


Square wave (Period = 2π seconds)
Amplitude
1
0
-1
-2pi
-pi
0
pi
2pi
Time (seconds)


Fourier sine series representation
Amplitude
1.5
1
0.5
0
0
pi
2pi
Period (seconds)


Fourier sine series representation
Amplitude
1.5
1
0.5
0
0
2
4
6
8
10
12
14
16
Frequency (Hz)