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 Use of shear wave velocity as a predictor of shaking
- D Frequency-dependent effects

II Ground response

$$\text{Ground response} = f(\underline{\text{source strength}}, \underline{\text{path}}, \text{"}\underline{\text{receiver}}\text{"})$$

A Equations are empirical but intended to capture physics

B Equation of Joyner and Boore (PP 1360: p. 204) for $5.0 \leq M_w \leq 7.7$

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

y = ground-motion parameter

c_x = frequency-dependent constants

M_w = Moment magnitude

$r = (d^2 + h^2)^{1/2}$:

d = dist. from surface trace of fault; h = pseudodepth

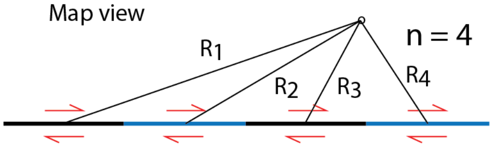
$S = 0$ (rock sites); $S = c_6 \log (V_{shear}/V_0)$ (soil sites)

II Ground response

Ground response = f(source strength, path, "receiver")

C Evernden's ground-motion equation (see lecture 10)
(PP 1360: p. 201)

$$I = 3(0.5+\log\left\{A\underline{\left(\frac{10^{11.8+1.5M}}{n}\right)}^{1/\underline{\gamma}}\underline{\left(\sum_{i=1}^{n}(R_i+C)^{-k\gamma}\right)}^{1/\underline{\gamma}}\right\})$$



Evernden's ground-motion equation

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- A = 0.779
- M = local magnitude
- n = # of fault segments
- γ = 0.25
- R = epicentral distance (km)
- C = pseudodepth (km)
- k = attenuation factor

Attenuation map showing values of k

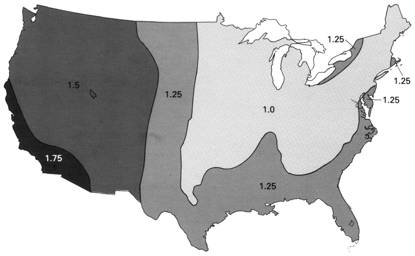


Fig. 66 of USGS Prof. Paper 1360

II Ground response

Ground response = f(source strength, path, "receiver")

D Arias Intensity (acceleration) equation (PP 1360: p. 331-333)

$$\log I_a = \underline{K_o + K_m M_w} - \underline{2 \log r} + \underline{K_\sigma P}$$

Duration of signal above threshold

Measured acceleration

$$I_A = \frac{\pi}{2g}\int_0^{T_d} a(t)^2\,dt$$

Gravitational acceleration

I_a = Arias intensity (units of m/sec)

K_o and K_m = constants

M_w = Moment magnitude

r = distance from slip surface (units of km)

$K_\sigma P$ = probability terms

(to account for path [geology] effects)

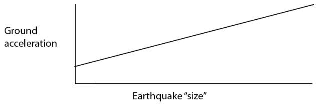
Has been useful for studying triggering of landslides

III Linear behavior

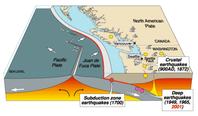
- A Assumption: the response to a small stimulus can be scaled up linearly to predict the response to a large stimulus
- B Ground response to artificial sources (e.g., Vibroseis, explosives) used to predict response to seismic waves

  (Even though strains from blasts are two orders of magnitude or so less than for earthquakes)
- C Ground response to little quakes Þ ground response to large quakes
- D Linear response <u>not</u> <u>adequate</u> to treat liquefaction phenomena; the near-epicenter response to large quakes is nonlinear.

Example of linear behavior



Cascadia earthquake sources



	Source	Affected area	Max. Size	Recurrence
●	Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
●	Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
●	Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

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

A $\varepsilon_{xy} = \dfrac{\sigma_{xy}}{2\mu}$

Strains are inversely proportional to shear modulus

B $V_s = \sqrt{\mu/\rho}$ ρ = density

Low V_s implies low μ

C Shear wave amplitude A

From Joyner and Fumal (1985, p. 203-220)

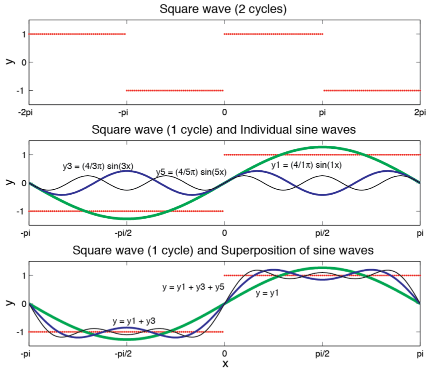
$$A \sim \frac{1}{\sqrt{\rho V_s}}$$

Decrease in V_s, μ , or ρ yields an increase in S-wave amplitude

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

IV Frequency-dependent effects

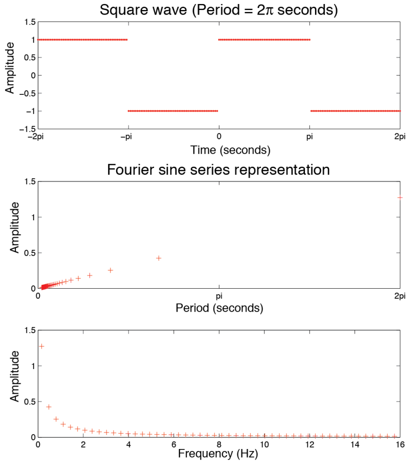
A Fourier analysis: represents a function of time (e.g. acceleration, velocity, displacement) as a function of frequency (f) or period (T), where f = 1/T.



Square wave (2 cycles)

Square wave (1 cycle) and Individual sine waves

Square wave (1 cycle) and Superposition of sine waves

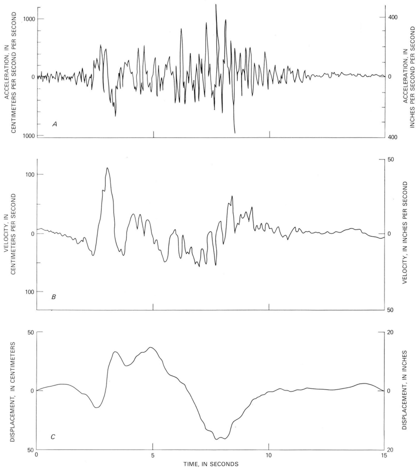


Square wave (Period = 2π seconds)

Fourier sine series representation

IV Frequency-dependent effects

- FIGURE 31.-Recordings of N. 14° E. component of horizontal ground motion at Pacoima damsite for 1971 San Fernando earthquake (from Page and others, 1975). Velocity (B) and displacement (C) records are obtained by integrating accelerogram (A) once and twice, respectively.



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IV Frequency-dependent effects

B Examples (from Prof Paper 1360, Rogers et al., p. 221-248)

1 Velocity vs. time responses at 8 sites in the Los Angeles region from nuclear tests in Nevada

2 Shaking velocities increase as alluvial thickness increases

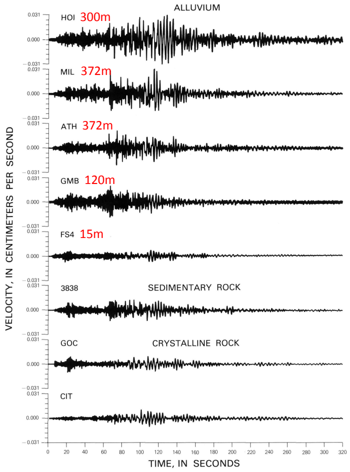

FIGURE 105.-Radial component time-histories of ground motion from a distant underground nuclear explosion in Nevada recorded simultaneously at eight sites in the Los Angeles region and grouped according to the type of geologic materials immediately beneath each recording station. The amplitude levels at locations underlain by alluvium clearly are greater than those at locations underlain by rock. The degree of amplification also appears to be related to the thickness of underlying alluvium: HOI, Holiday Inn, 300 m; MIL, Millikan Library, 372 m; ATH, Athenaeum, 372 m; MB, Glendale Municipal Building, 120m; FS4, Fire Station 4, 15 m. GOC, CIT, and 3838 are rock sites.

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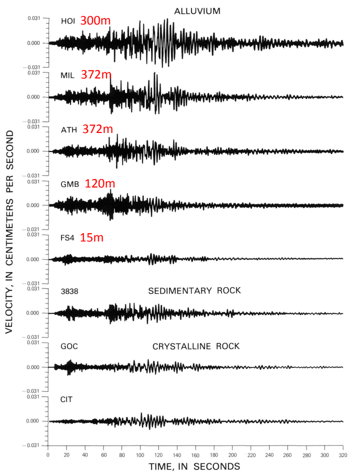

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V Frequency-dependent effects

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

1 T < 0.5 sec (f > 2 Hz) Shaking on Quaternary sedimentary deposits is 3-4 times that of sites founded on crystalline rock

2 T > 0.5 sec (f < 2 Hz) Shaking increases as thickness of Quaternary deposits increases and/or as depth to basement rock increases

- a Ground motion depends on $\mu_{\text{"average"}}$
- b $\mu_{\text{Quat. deposits}} < \mu_{\text{Basement rocks}}$

Velocity spectra relative to bedrock (CIT) site

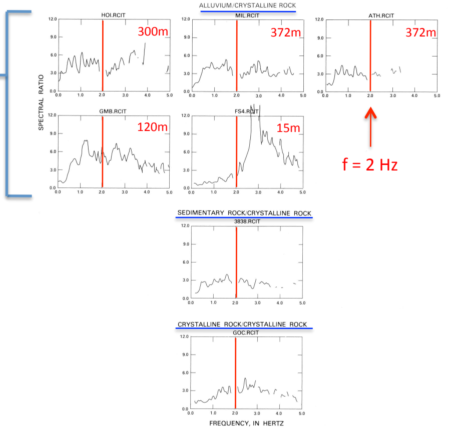
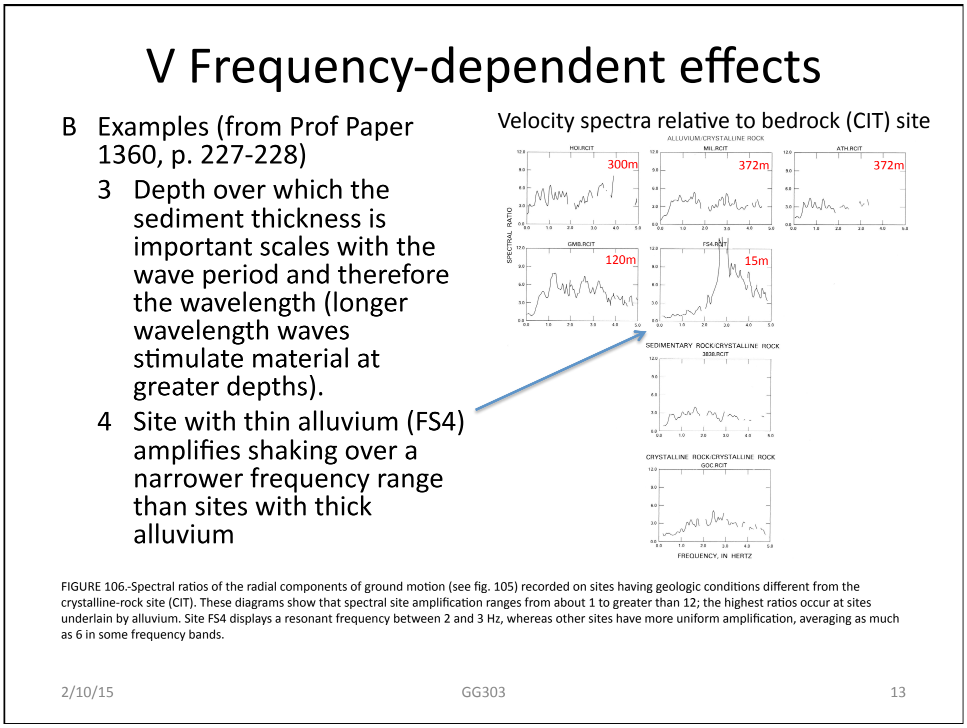


FIGURE 106.-Spectral ratios of the radial components of ground motion (see fig. 105) recorded on sites having geologic conditions different from the crystalline-rock site (CIT). These diagrams show that spectral site amplification ranges from about 1 to greater than 12; the highest ratios occur at sites underlain by alluvium. Site FS4 displays a resonant frequency between 2 and 3 Hz, whereas other sites have more uniform amplification, averaging as much as 6 in some frequency bands.



V Frequency-dependent effects

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

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 Site with thin alluvium (FS4) amplifies shaking over a narrower frequency range than sites with thick alluvium

Velocity spectra relative to bedrock (CIT) site

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