Earthquake Ground Motions

Kramer 1996

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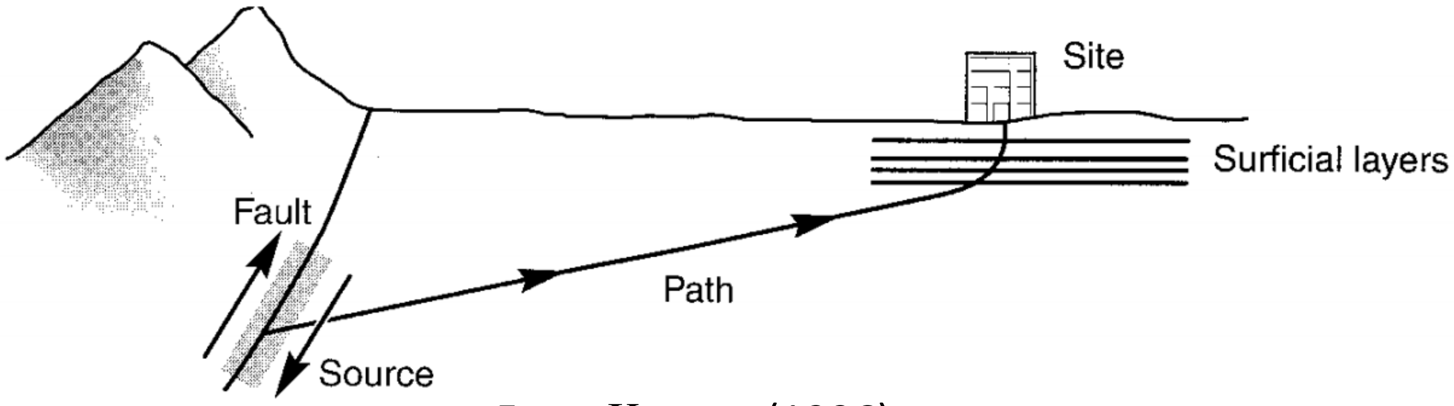
UNIVERSITY OF ARKANSAS

One of the Primary Goals of Geotechnical Earthquake Engineers is to Predict:

- **Intensity (Amplitude)**
- **Frequency Content**
- **Duration**

for seismic ground motions from the fault source to the site of interest.



From Kramer (1996)

What Parameters effect Intensity, Frequency Content, and Duration?

- Earthquake Magnitude
- Distance from the fault (near fault effects)
- Site Conditions (local, near surface)
- Fault type/tectonic setting
- Travel Path Geology (Deep in the earth) (Eastern vs Western Rock)
- Special Effects
  - Directivity, basin/topographic

With every Earthquake our database of recorded ground motions increases. This helps us further understand how the parameter listed above affect ground motions.

Most earthquake ground motions are presently recorded with accelerometers.

Small amplitude ground motions may be recorded using velocity meters.

Ground Motion Recording Network

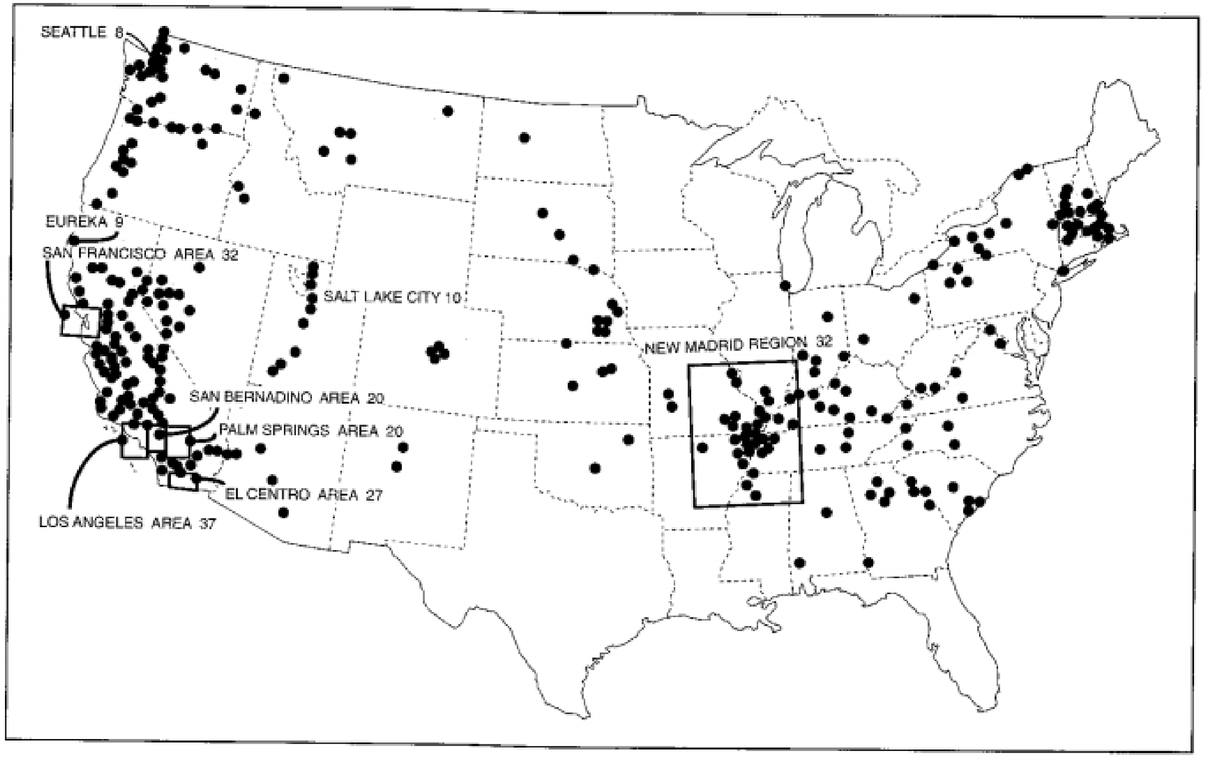
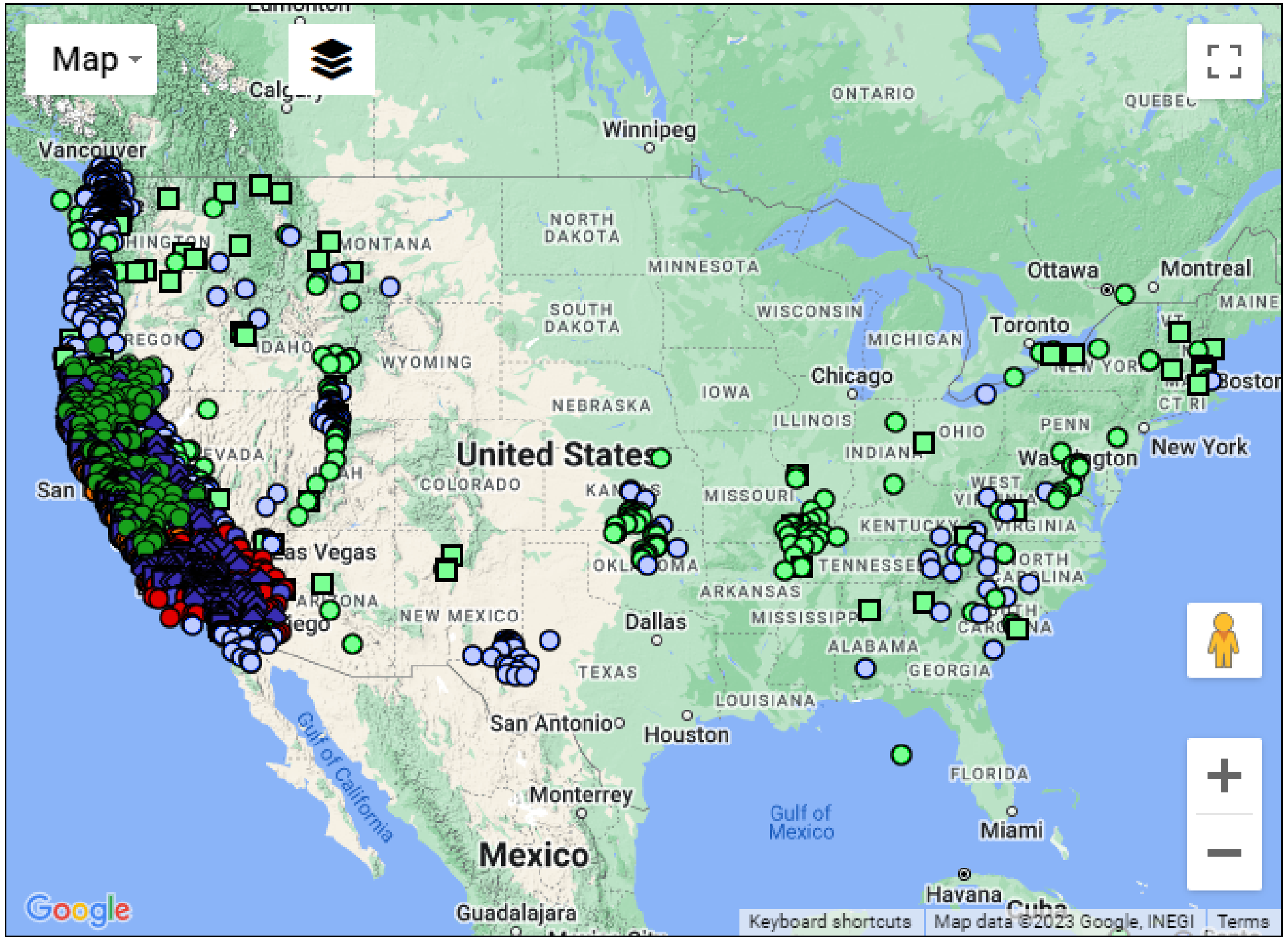
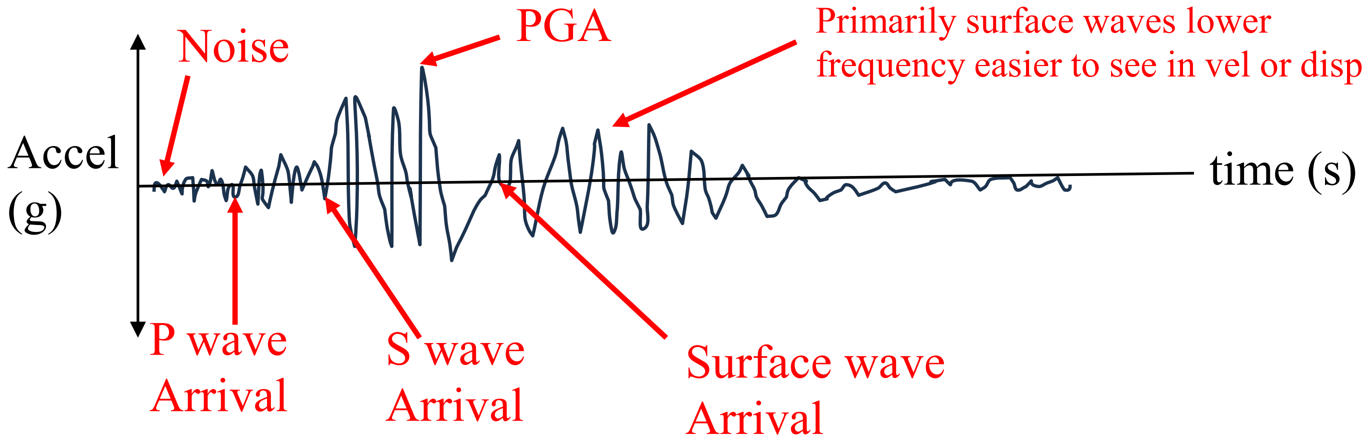


Figure 3.6 Locations of strong motion instruments operated by the U.S. Geological Survey in cooperation with other agencies as of April, 1990. Boxes in northern and southern California indicate areas with high instrument density. (After Joyner and Boore, Geotechnical News, March, 1991, p. 24. Used by permission of BiTech Publishers, Ltd..)



Earthquake Ground Motions



As recordings are made further from Earthquake epicenter

- Intensity: Peak Ground Acceleration (PGA) decreases (attenuate)
- P, S waves: separate more at distance 2*thickness of the crust (~50 miles) Surface wave amplitudes produce peak GM's at larger distances.
- Frequency content: As distance increases, high frequencies attenuate (because the earth is a low pass filter and as distance increases high frequencies will damp out)
- Duration: As distance increases, duration increases

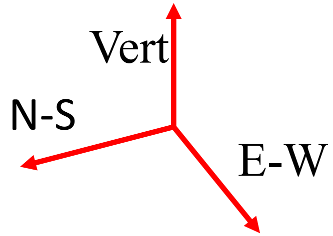
Earthquake Ground Motions

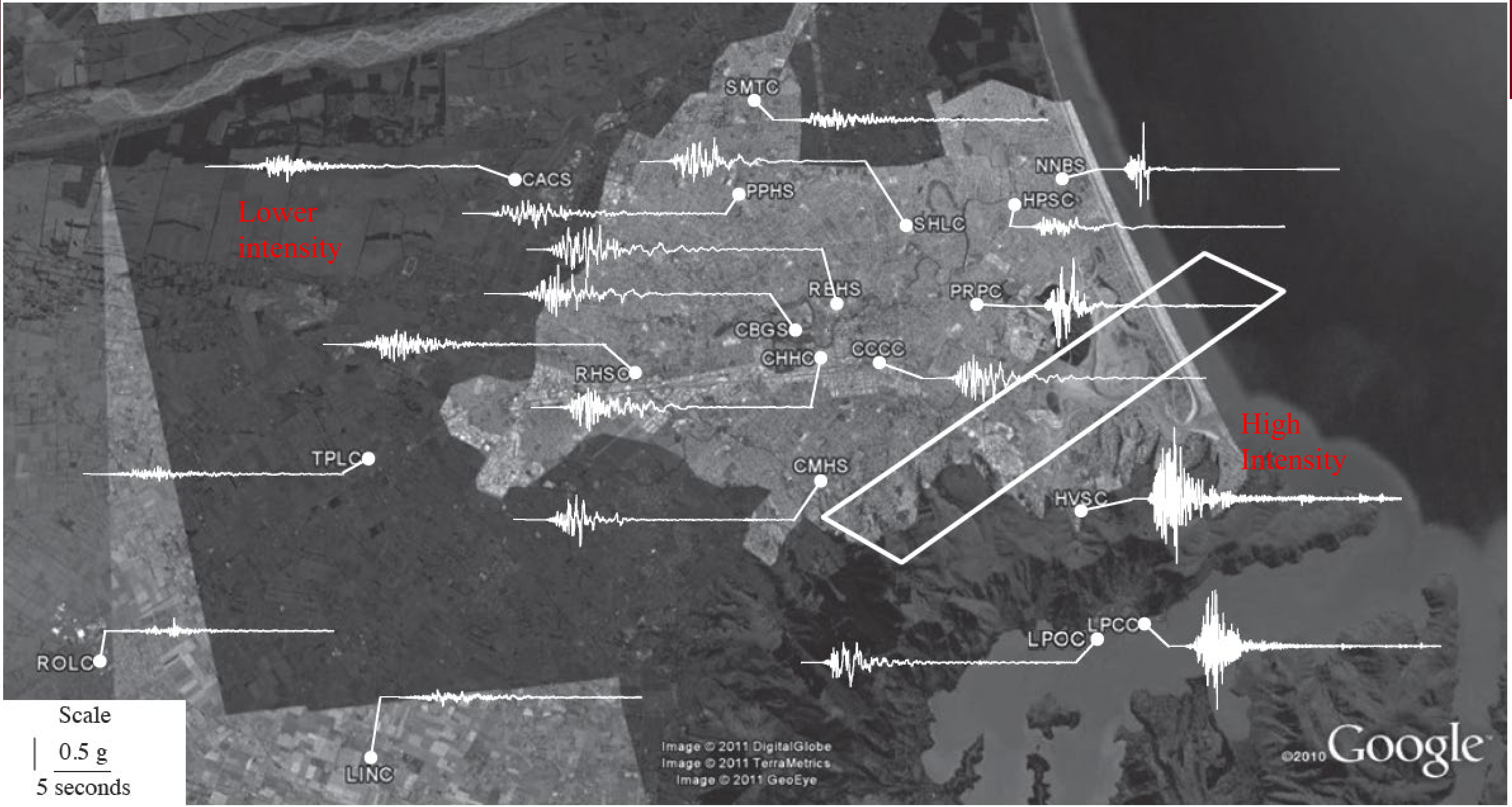
1. <u>Intensity (amplitude)</u>

- Generally, measure motions in 3 orthogonal directions (Vert, N-S, E-W). Can transform to fault parallel, fault horizontal.
- The basic form is the ground motions are time histories (time versus acceleration).
- Often directly measure acceleration for strong ground motion and integrate to get velocity and displacement.

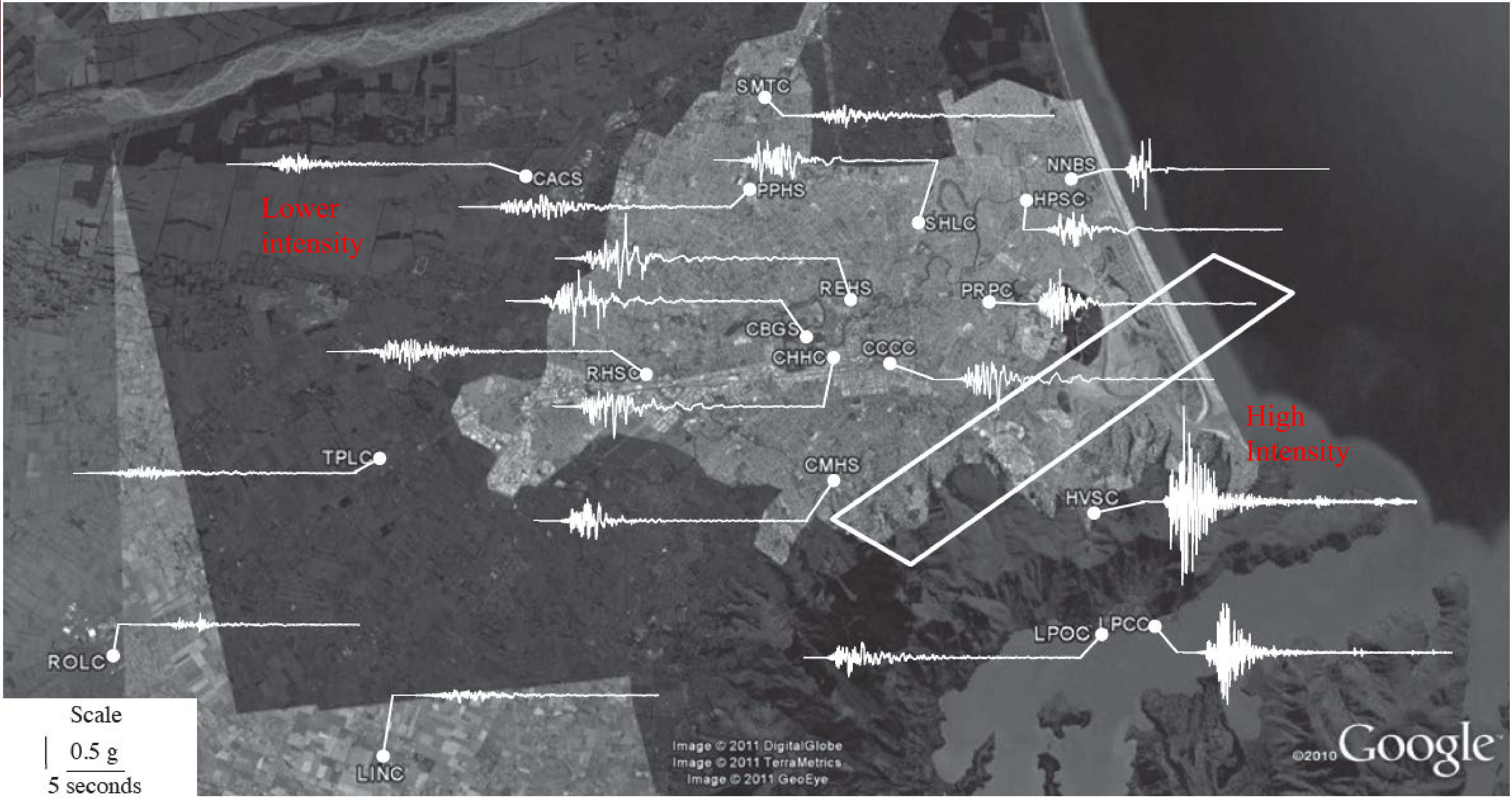
Accelerometer

Seismometer
(Velocity Meter)





▲ **Figure 4.** Observed fault-normal horizontal acceleration time histories at various locations in the Christchurch region from the 22 February earthquake.



▲ **Figure 5.** Observed fault-parallel horizontal acceleration time histories at various locations in the Christchurch region from the 22 February earthquake.

Earthquake Ground Motions

1. Intensity (amplitude)

- Engineers typically assume horizontals motions are more damaging than vertical motions. Vertical motions can be important for rotating or sensitive equipment or structures.
  - Factors of safety against gravity-induced static vertical forces in buildings usually provides adequate resistance to vertical forces during earthquakes

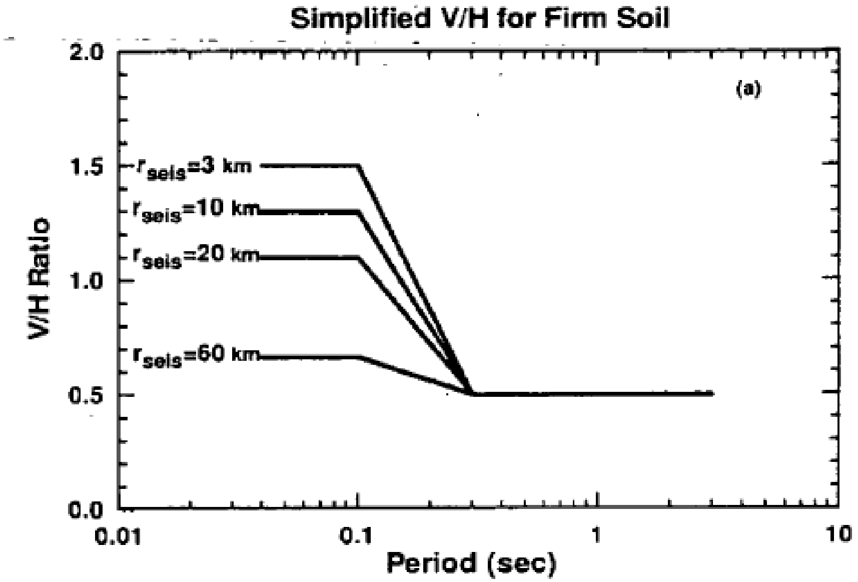
$Max\ Vert\ Accel\ (MVA) = \frac{2}{3}\ Max\ Horz\ Accel\ (MHA)$ (old school of thought not always true)

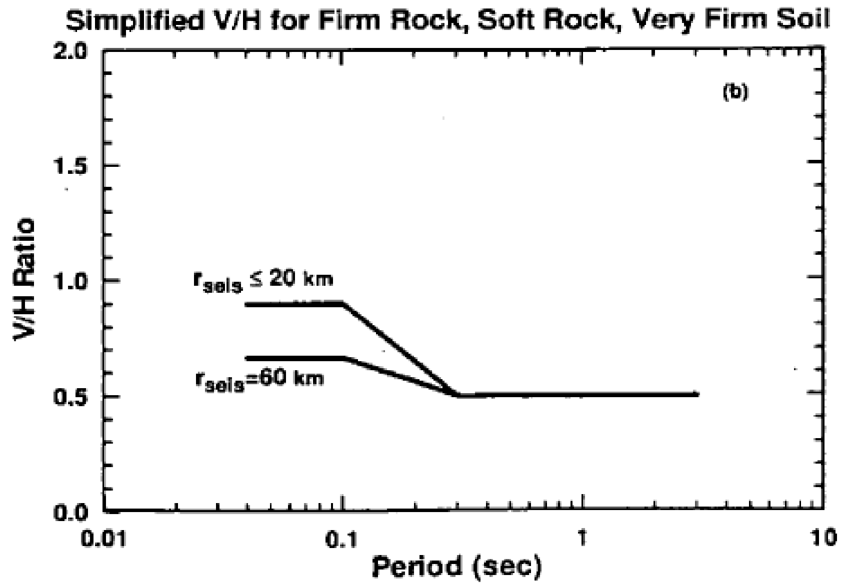
Typically, V/H ratios are used to estimate the vertical spectrum.

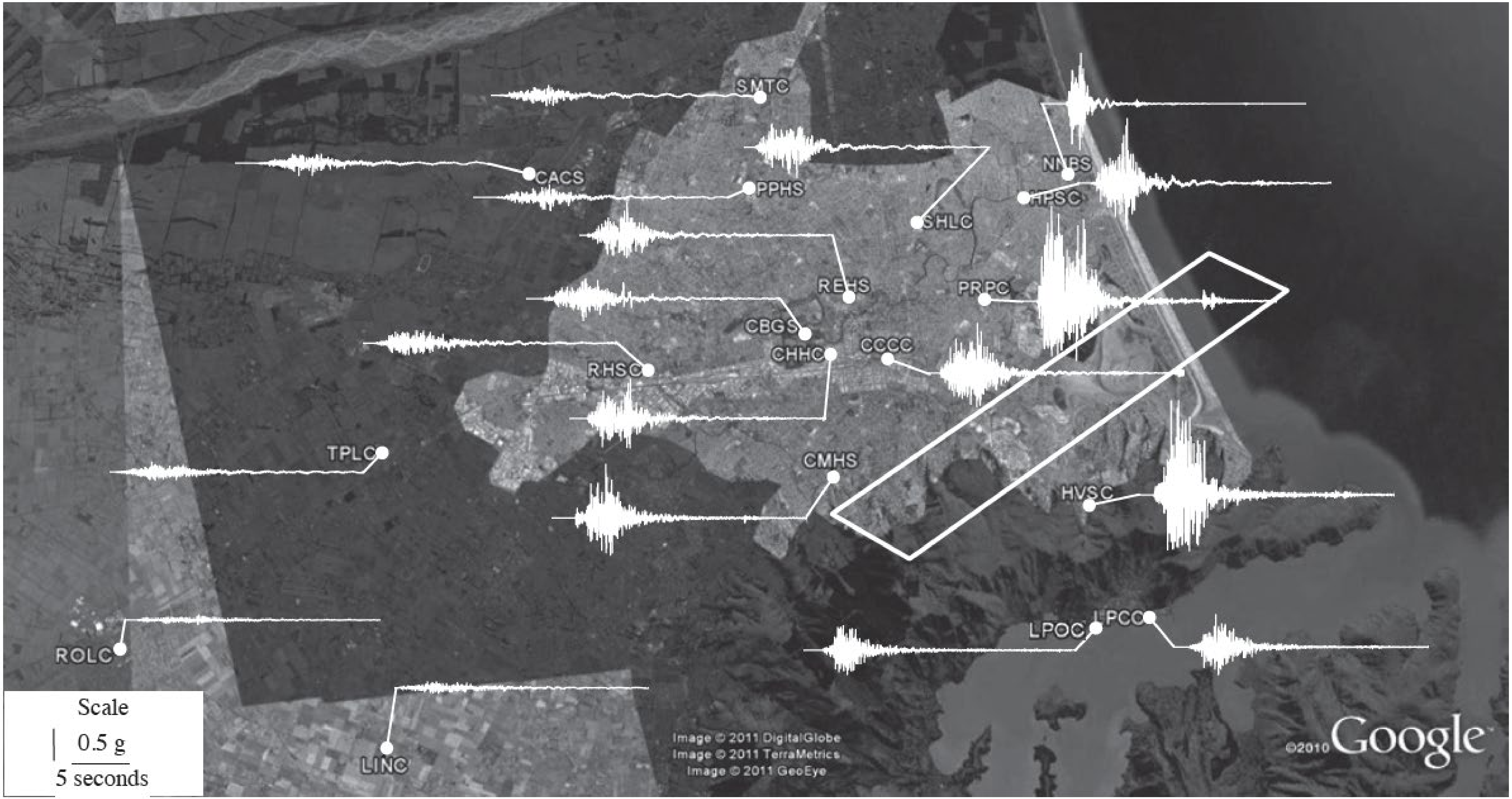
Bozorgnia and Campbell (2004) is generally considered the standard for V/H ratios, but newer approaches are available.

ASCE 7-16 code addresses vertical ground motions.

V/H can be very large (2-5 in certain frequency ranges) if large Horz ground motions are expected.







▲ **Figure 6.** Observed vertical acceleration time histories at various locations in the Christchurch region from the 22 February earthquake.

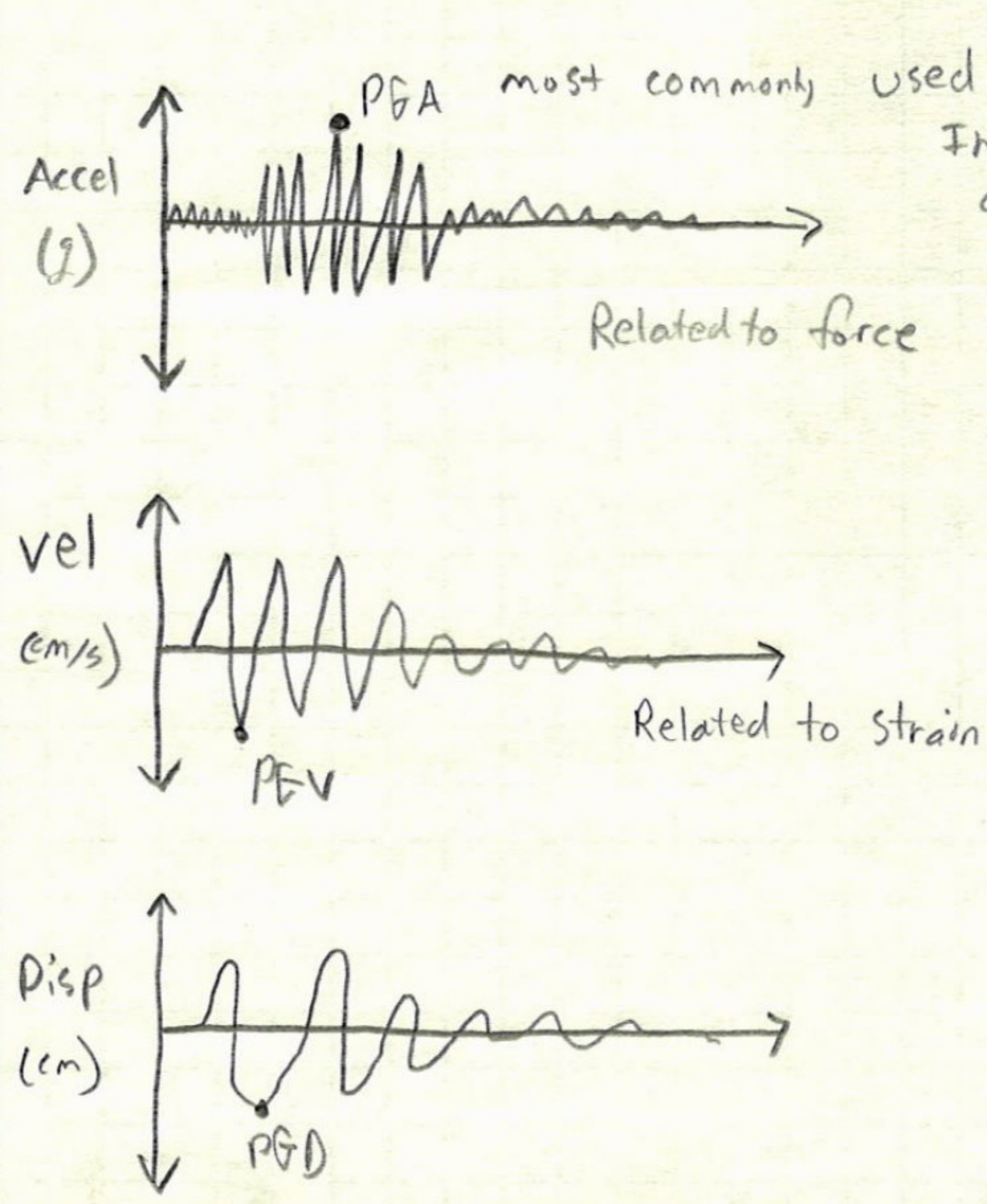
Earthquake Ground Motions

1. **Intensity (amplitude)**

- Main parameters used
  - Peak Ground Acceleration (PGA)
    - Most commonly used ground motion parameter
    - Largest value of horizontal acceleration, absolute
    - In general, as PGA goes up, damage goes up, but it is dependent on building period.

  - Peak Ground Velocity (PGV)
    - More accurate at intermediate frequencies since less sensitive to high frequencies, may be a better indicator of potential damage.

  - Peak Ground Displacement (PGD)
    - Typically associated with low frequency content, less common since errors can occur during signal processing.



Earthquake Ground Motions

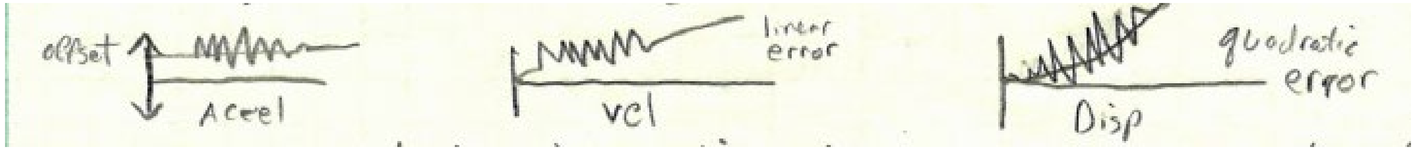
1. <u>Intensity (amplitude)</u>

- Numerically integrate (Trapezoidal rule) the acceleration time history to get Velocity and displacement time histories

- “Loose” high frequency components when we move from ACC to Disp and the amplitude of the low freq. will increase

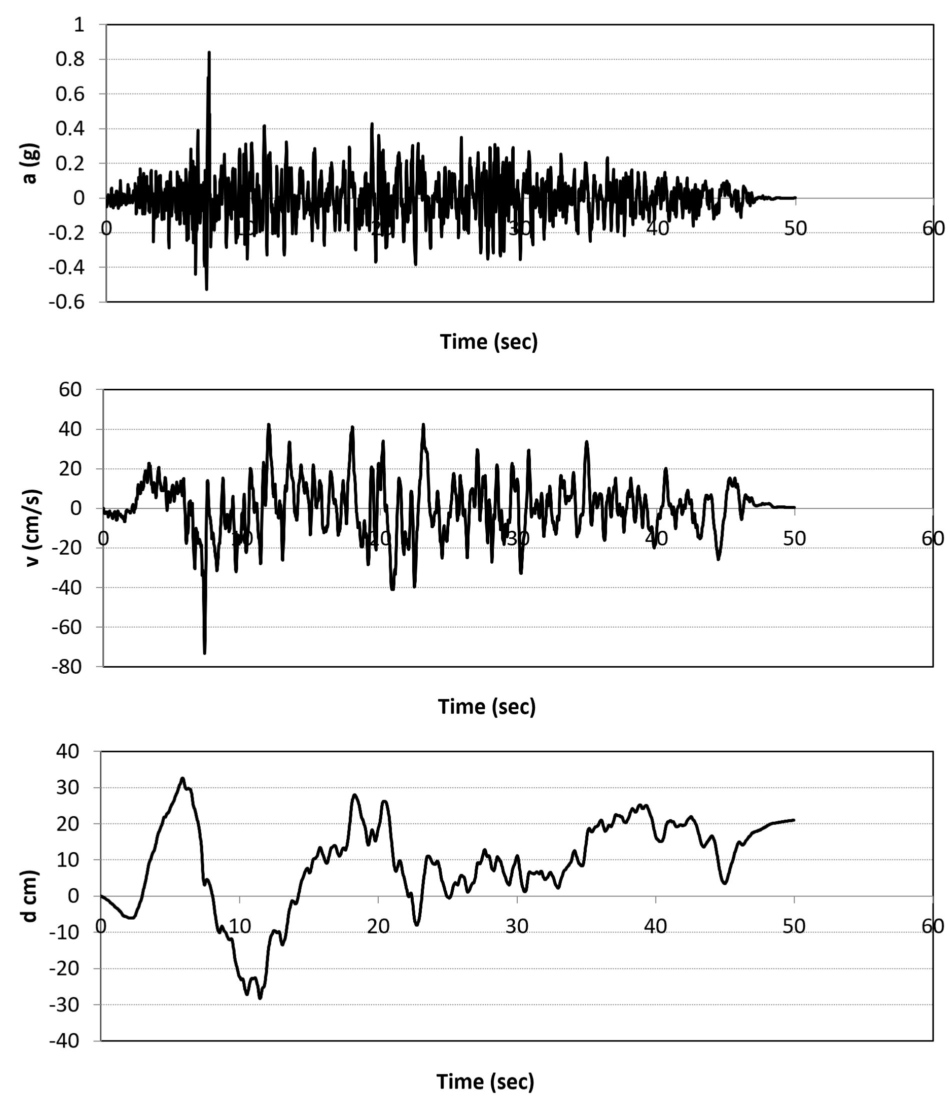
    - Remember in frequency domain $D = \frac{A}{\omega^2}$ and V= $\frac{A}{\omega}$

- Acceleration time histories are processed for:
    - Instrument response (calibration factors) must account for building response if located in building
    - Ambient noise (filtering)
    - Conditions at triggering (baseline correction)



In the time domain fit a function to acceleration record and subtract
In frequency domain, apply high pass filter above ~ 0.1 Hz

Landers Earthquake



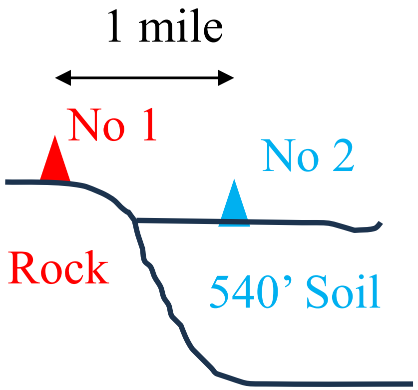
Earthquake Ground Motions

1. **Intensity (amplitude)**

- Local site condition affect intensity.
  - Gilroy 1 (sandstone rock)
  - Gilroy 2 (540’ of soil)
  - Less than 1 mile apart

Thick soil layers attenuate high frequencies and amplify low Frequencies.

Duration increases on soil



Parameter	Gilroy No. 1 (Rock)	Gilroy No. 2 (Soil)
Peak acceleration	0.442*g*	0.332*g*
Peak velocity (cm/sec)	33.7	39.2
Peak displacement (cm)	8.5	13.3

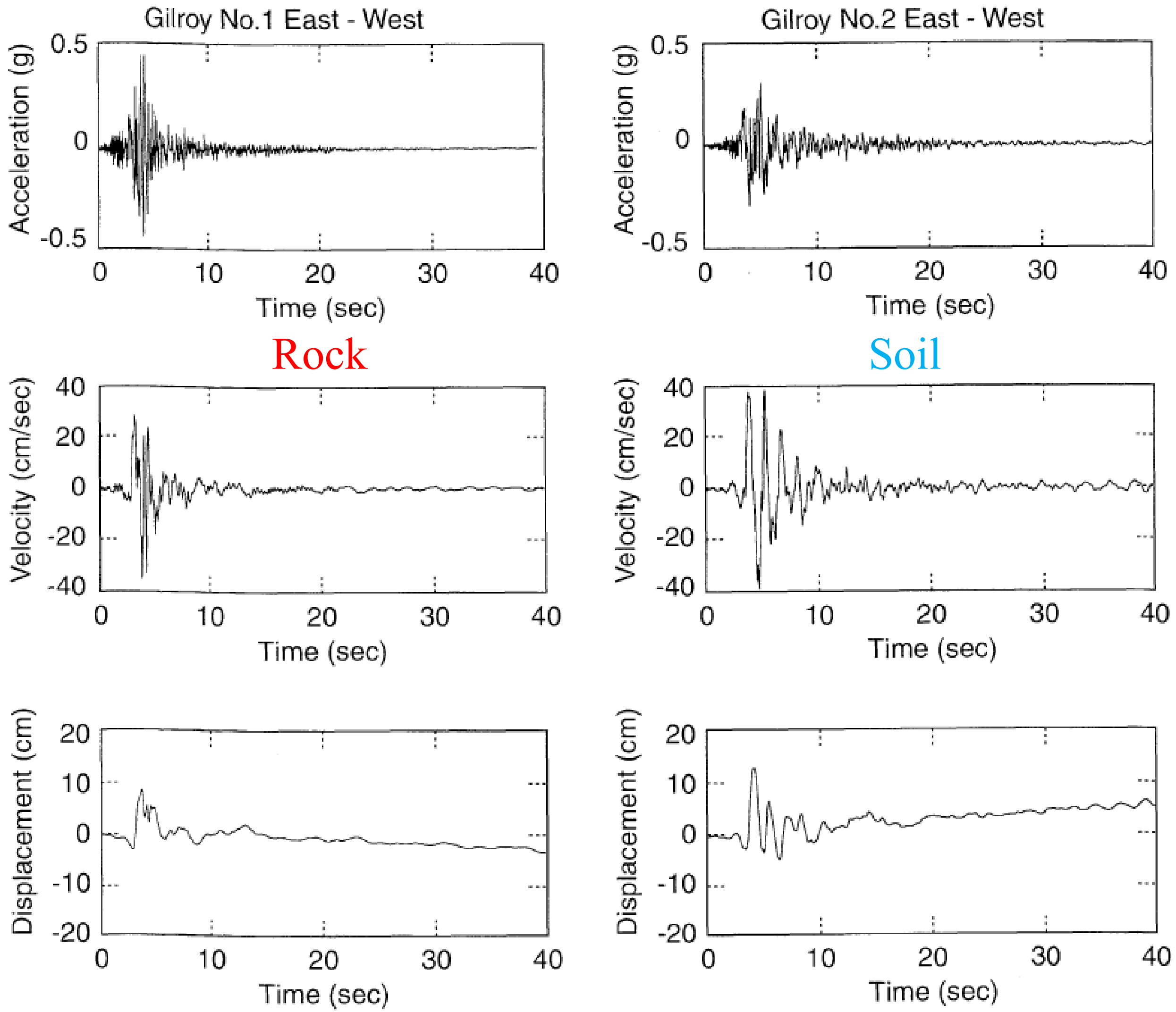


Figure 3.10 Acceleration, velocity, and displacement time histories for the E-W components of the Gilroy No. 1 (rock) and Gilroy No. 2 (soil) strong motion records. The velocities and displacements were obtained by integrating the acceleration records shown in Figure 3.1 using the trapezoidal rule. Note that the Gilroy No. 1 (rock) site experienced higher accelerations, but the Gilroy No. 2 (soil) site experienced higher

Earthquake Ground Motions

1. <u>Intensity (amplitude)</u>

- What is the potential problem with just using PGA?

Damage may be closely related to PGA in many cases, but other cases repeated applications of high amplitude cycles are more damaging

For the Melendy Ranch recording station:

The 1972 Stone Canyon Earthquake (M=4.6) and the 1967 Koyna Earthquake (M=6.5) have the same PGA, but the Koyna record has many more cycles of high amplitude than the Stone Canyon record.

1972 Stone Canyon Earthquake (M=4.6) 1967 Koyna Earthquake (M=6.5)

(a) (b)

Figure 3.12 Accelerograms from (a) the N29W Melendy Ranch record of the 1972 Stone Canyon (M = 4.6) earthquake and (b) the longitudinal record from the 1967 Koyna (M = 6.5) earthquake. The time and acceleration scales are identical for both records. Peak accelerations are very close, illustrating the limitations of using peak amplitude as a sole measure of strong ground motion. (After Hudson, 1979; used by permission of EERI.)

Earthquake Ground Motions

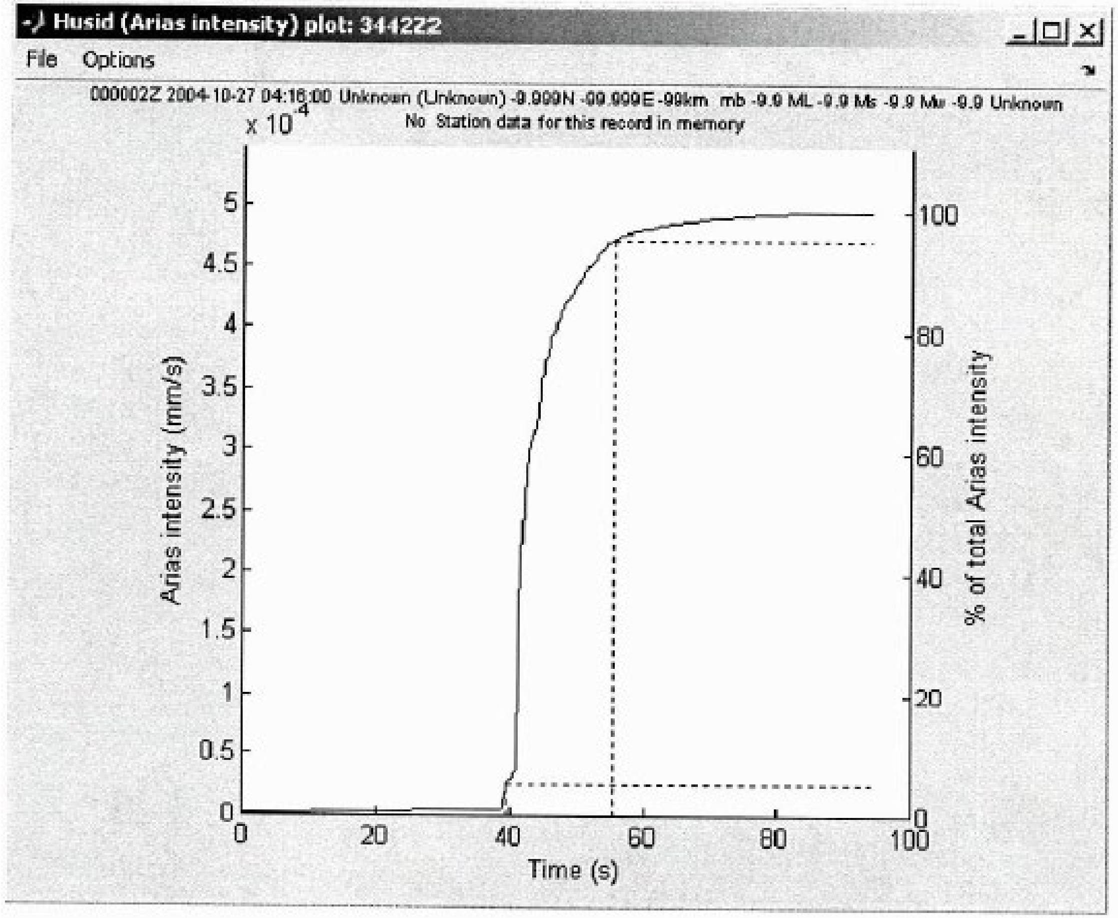
1. Intensity (amplitude)

- Other measures of Intensity:
  - **Arias Intensity**
    - Takes into account the entire time history, not just one value.

$$I_a = \frac{\pi}{2g}\int_0^{t_{\max}} a^2(t)\,\mathrm{d}x \quad \text{Velocity Units}$$

where I_a is in units of m/s, $a(t)$ is the ground acceleration in g, g is the acceleration of gravity, and $t_{\max}$ is the total duration of the recorded time history.

  - **Husid Plot (Ia versus time)**
    - Can be used to define duration too.

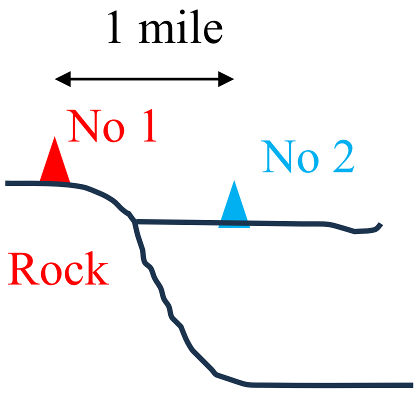


Earthquake Ground Motions

2. Frequency Content

- Fourier Amplitude Spectra (FAS)
    - Predominate Period (Tp)

Thick soil layers attenuate high frequencies and amplify low Frequencies.



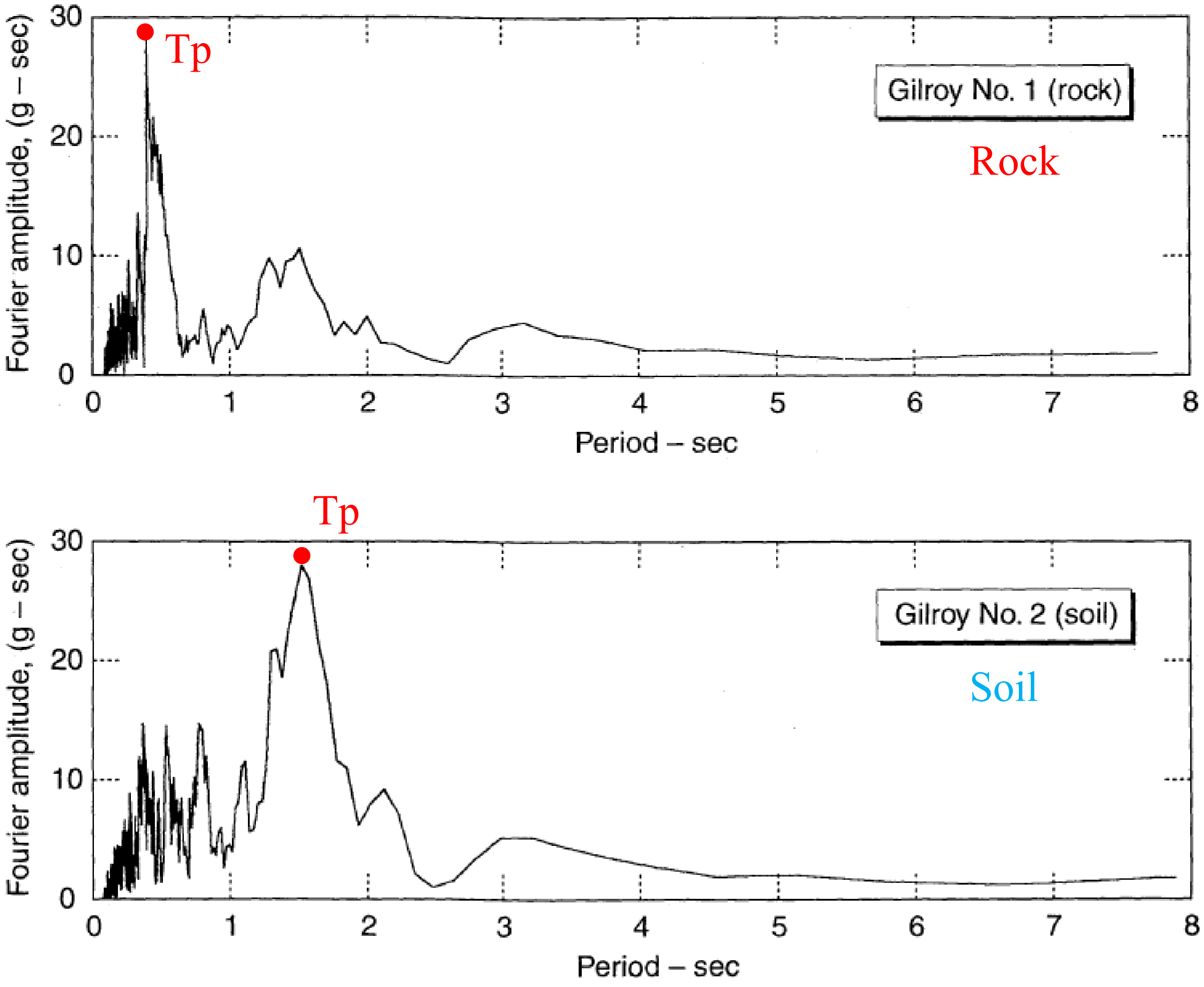
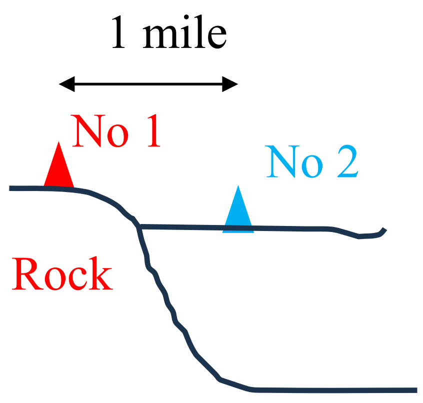


Figure 3.13 Fourier amplitude spectra for the E-W components of the Gilroy No. 1 (rock) and Gilroy No. 2 (soil) strong motion records. Fourier spectra were obtained by discrete Fourier transform (Section A.3.3 of Appendix A) and consequently have units of velocity. Fourier amplitude spectra can also be plotted as functions of frequency (see Figure E3.3).

Earthquake Ground Motions

2. Frequency Content

- Response Spectrum
  - Response of SDOF systems with given damping
  - Input to response spectrum is the time domain equivalent of the FAS
  - Generally, earthquake Frequencies are 0.2-20 Hz



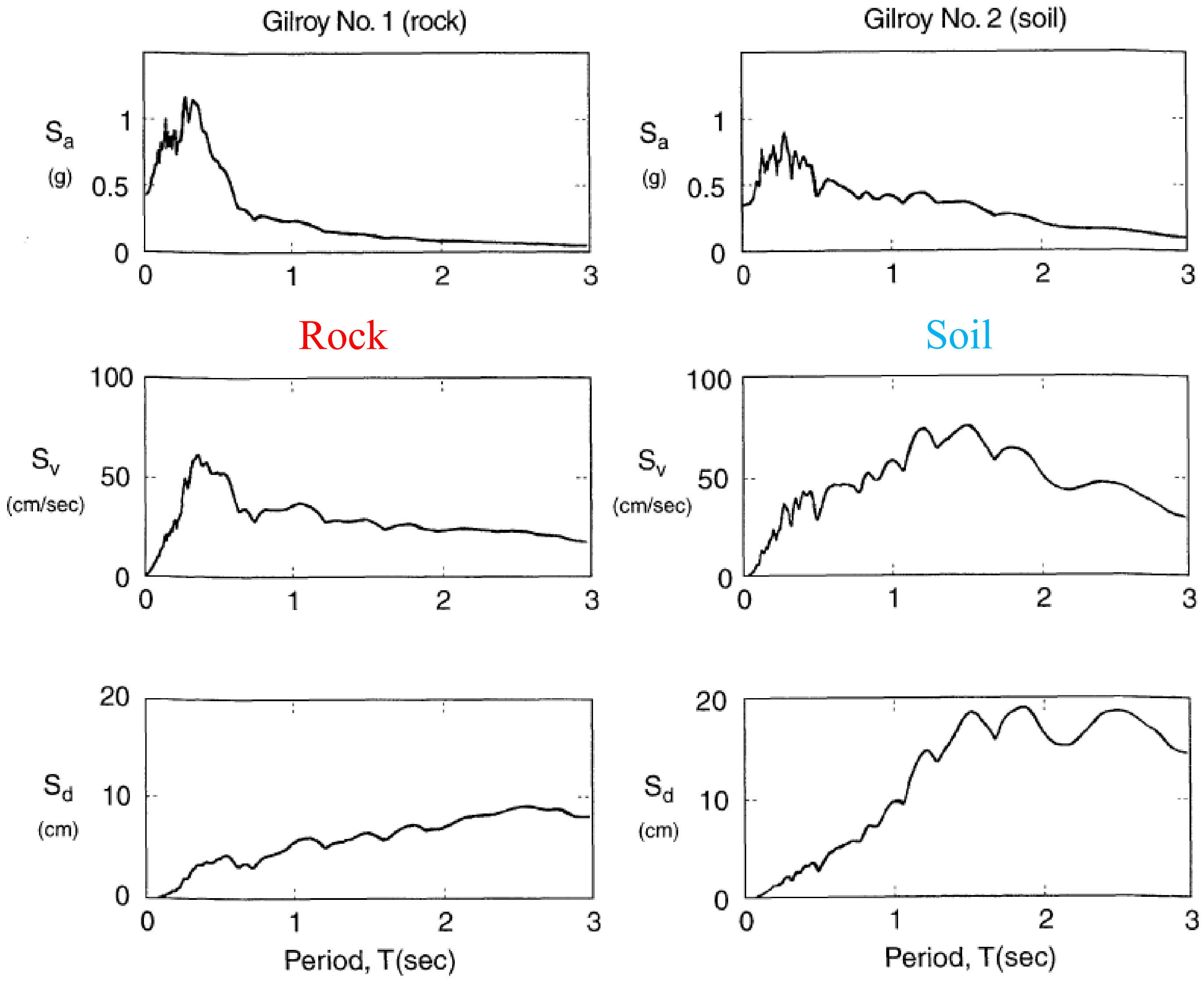


Figure 3.15 Response spectra (5% damping) for Gilroy No. 1 (rock) and Gilroy No. 2 (soil) strong motion records. The frequency contents of the two motions are reflected in the response spectra. The Gilroy 1 (rock) motion, for example, produced higher spectral accelerations at low periods than did the Gilroy 2 (soil) motion, and lower spectral accelerations at higher periods. The higher long-period content of the Gilroy 2 (soil) motion produced spectral velocities and displacements much higher than those of the Gilroy 1 (rock) motion.

Earthquake Ground Motions

3. Duration

- Number of cycles of loading
  - Affects
    - Degradation of stiffness and strength
    - Pore pressure build-up

- Lower Amplitude and Longer Duration may produce more damage than Higher Amplitude and Shorter Duration

Table 3-3 Equivalent Number of Uniform Stress Cycles

Earthquake Magnitude	Number of Significant Stress Cycles
$5\frac{1}{4}$	2–3
6	5
$6\frac{3}{4}$	10
$7\frac{1}{2}$	15
$8\frac{1}{2}$	26

Table 3-2 Typical Earthquake Durations at Epicentral Distances Less Than 10 km

	Duration (sec)	
Magnitude	Rock Sites	Soil Sites
5.0	4	8
5.5	6	12
6.0	8	16
6.5	11	23
7.0	16	32
7.5	22	45
8.0	31	62
8.5	43	86

Source: Chang and Krinitzsky (1977).

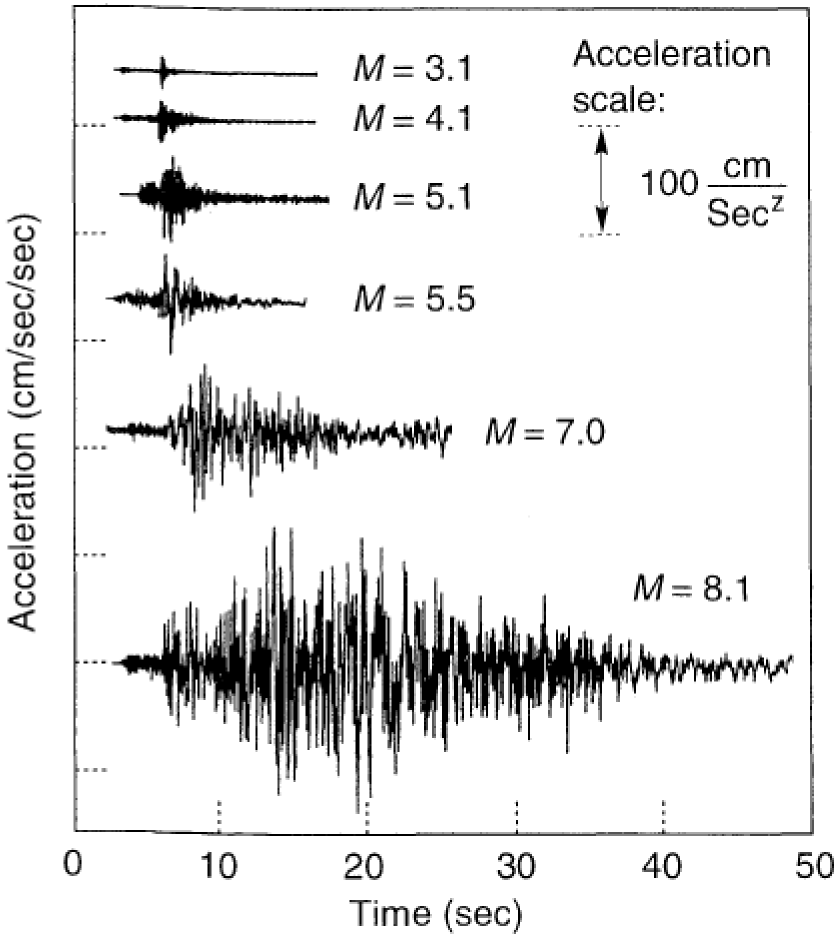


Figure 3.20 Accelerograms from six earthquakes off the Pacific coast of Mexico. Each accelerogram was measured at nearly the same epicentral distance. The record from the $M = 8.1$ (1985 Michoacan) earthquake continues for another 25 sec. (After Anderson, 1991, *Geotechnical News*, Vol. 9, No. 1, p. 35. Used by permission of BiTech Publishers, Ltd.)

Earthquake Ground Motions

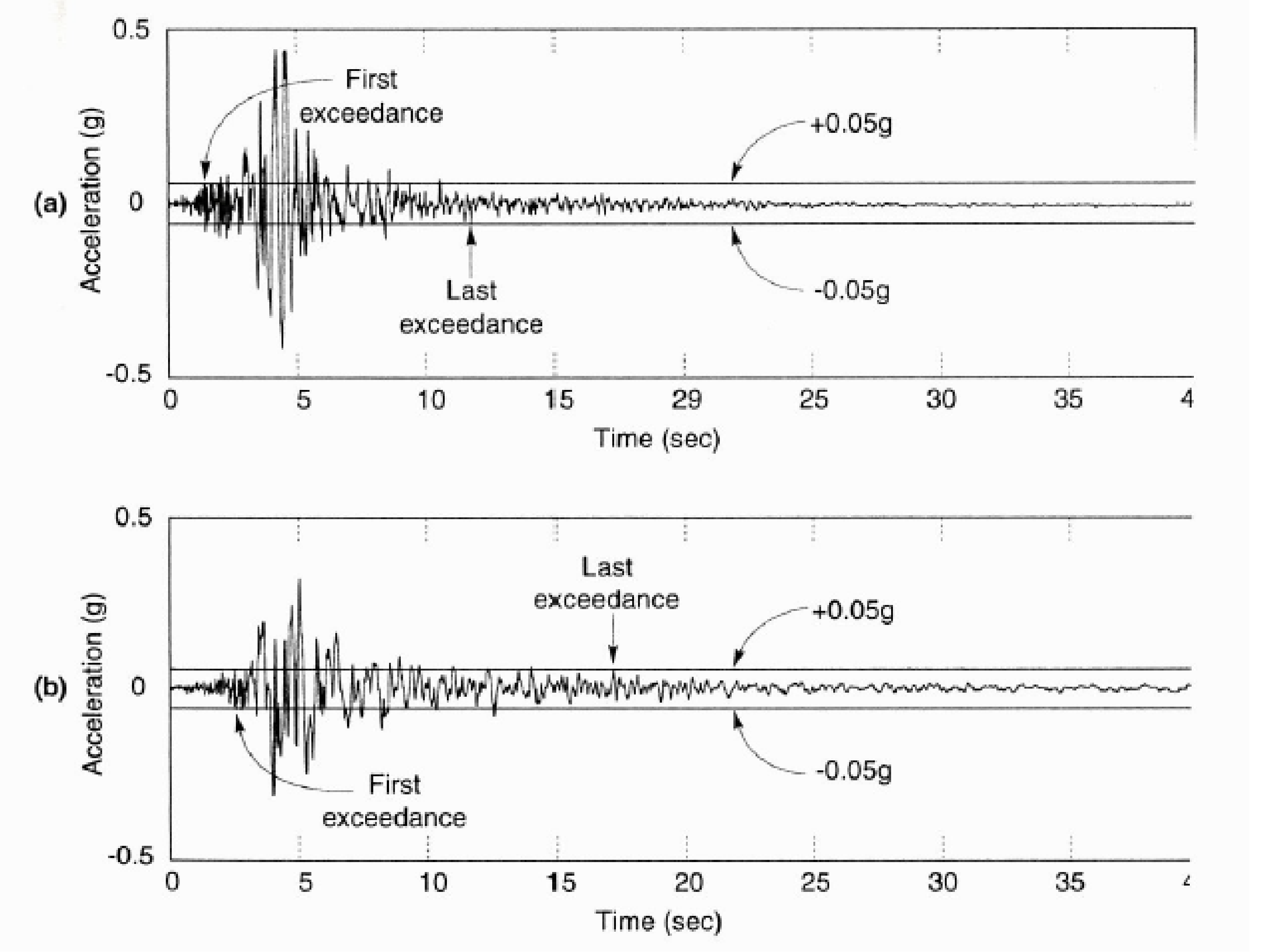
3. <u>Duration</u>

- Bracketed Duration (exceed 0.05g)

Gilroy No 1 (Rock) = 9.8 sec

Gilroy No 2 (Soil) = 14.7 sec

*problem: further locations may not have a duration.

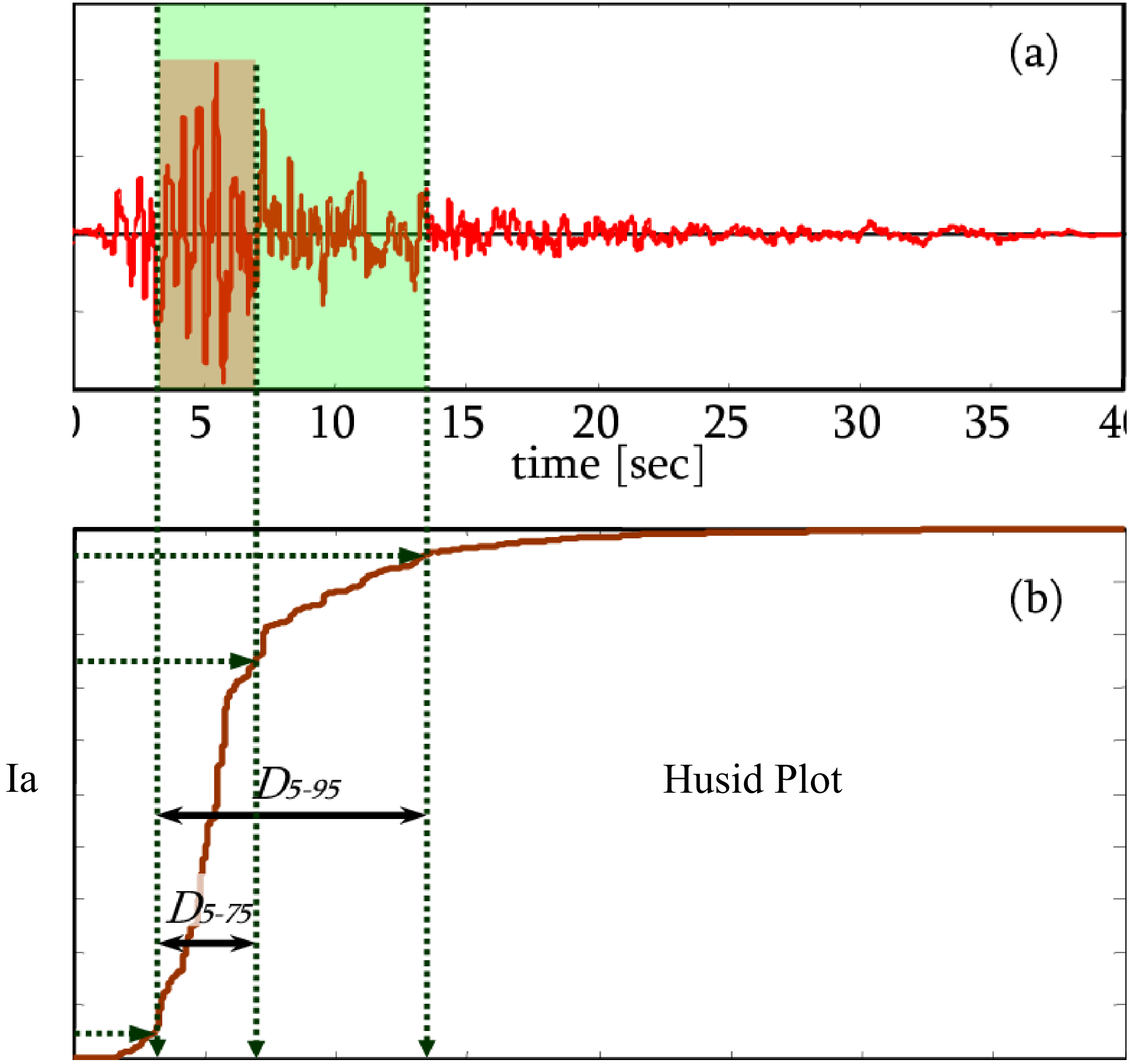


Earthquake Ground Motions

3. **Duration**

- Significant Duration
  - Based on Arias Intensity
  - Defined as the time interval across which a specified amount of energy is dissipated.

  - Two common measures of significant duration are time intervals between 5-75% and 5-95%

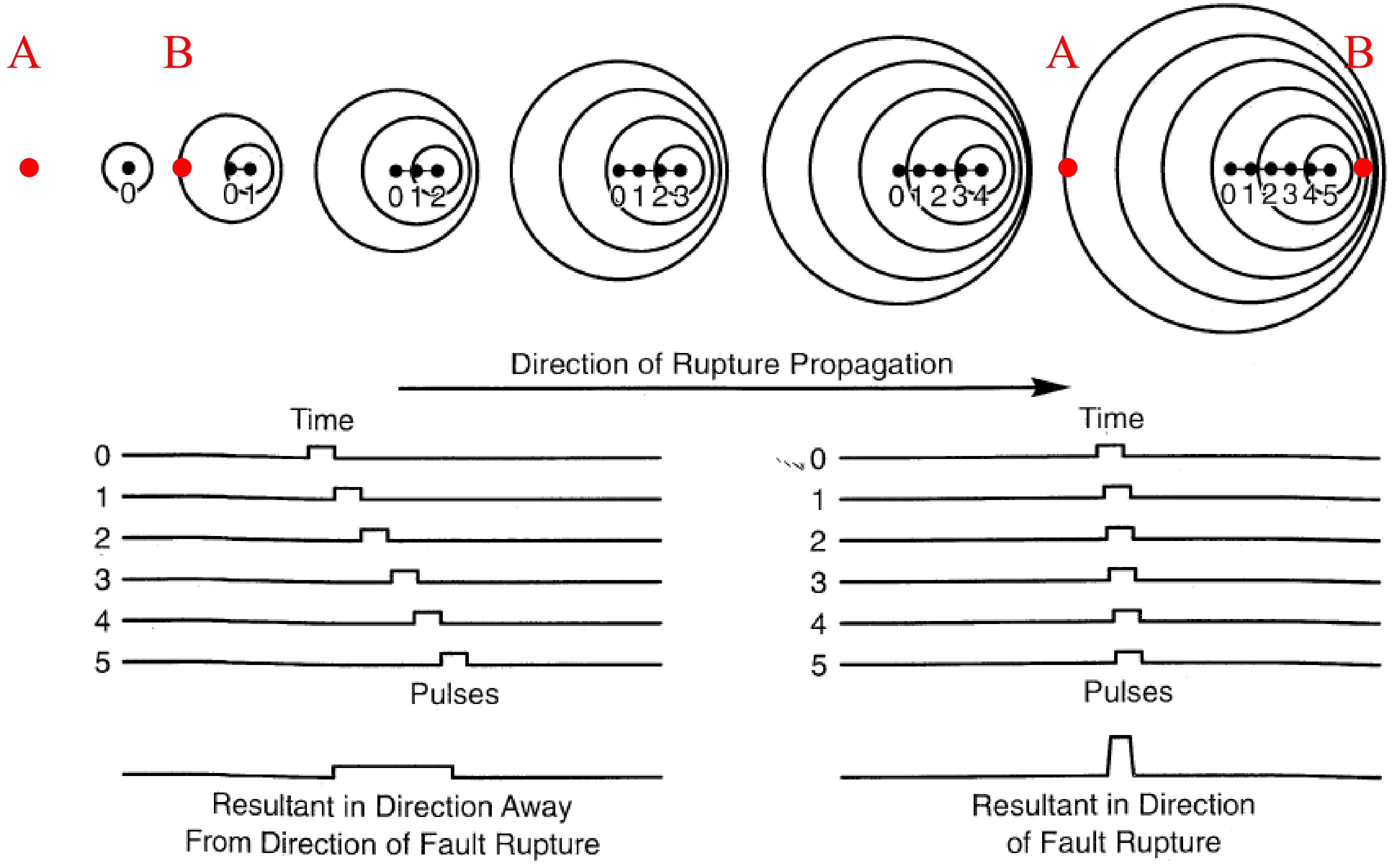


Earthquake Ground Motions

Near Fault Effects

- Near fault effects are for distances (R) < 10-20 km from fault

1. Rupture directivity: enhanced long-period energy when fault ruptures toward the site (forward directivity).
    - Fault rupture is like ripping a piece of cloth. The rupture can initiate and rip either or both directions.
    - The fault ruptures propagates at a velocity approximately equal to Vs (~ 3 km/sec)
    - Each rupture point is initiating shear waves that radiate away from that point
    - All shear waves arrive at B at the same time producing a high amplitude, short duration pulse (Forward Directivity)
    - S-waves arrive at A all spread out producing a low amplitude, long duration pulse (Backward Directivity)



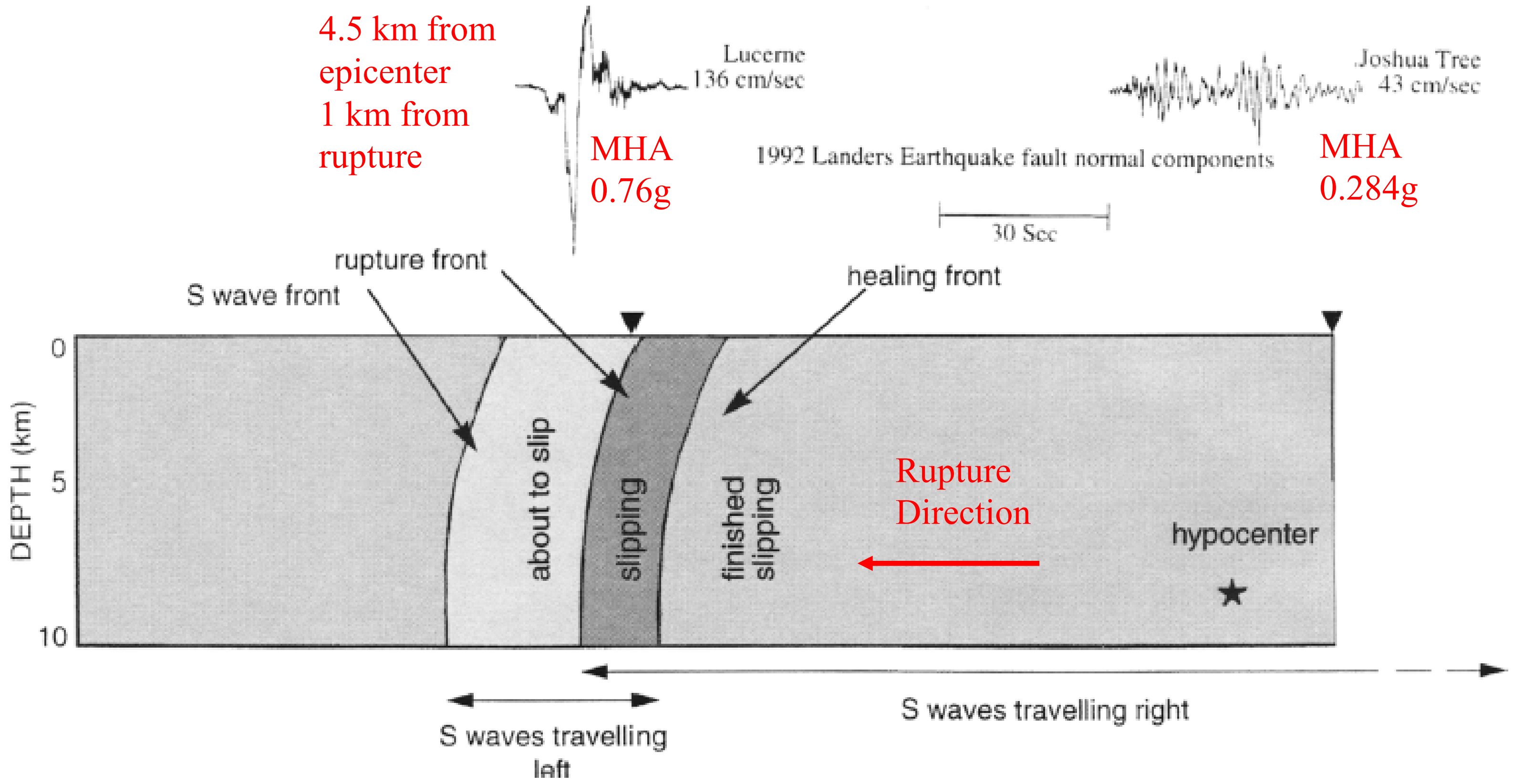
Earthquake Ground Motions

Near Fault Effects

Somerville et al. (1997)

1992 Landers Earthquake (Mw = 7.3) Southern Cal.
(Lucerne vs Joshua Tree record.)

- Forward Directivity
  - Large 2-sided Velocity Pulse
  - Increased Low Frequency Content (Long Period)
  - Short Duration Pulse
  - Manifests primarily in the Fault Normal direction due to radiation pattern of S-wave



The conditions required for forward directivity are also met in dip-slip faulting, including both reverse and normal faults. The alignment of both the rupture direction and the slip direction up the fault plane produces rupture directivity effects at sites located around the surface exposure of the fault (or its updip projection if it does not break the surface).

Forward rupture directivity effects occur when two conditions are met: the rupture front propagates toward the site, and the direction of slip on the fault is aligned with the site. The conditions for generating forward rupture directivity effects are readily met in strike-slip faulting, where the fault slip direction is oriented horizontally in the direction along the strike of the fault, and rupture propagates horizontally along strike either unilaterally or bilaterally. However, not all near-fault locations experience forward rupture directivity effects in a given event. Backward directivity effects, which occur when the rupture propagates away from the site, give rise to the opposite effect: long duration motions having low amplitudes at long periods, as shown in Figures 1 and 3. A qualitative description of these effects was presented by Archuleta and Hartzell (1981) using data from the 1979 Imperial Valley earthquake.

Earthquake Ground Motions

Near Fault Effects

Somerville et al. (1997)

1992 Landers Earthquake (Mw = 7.3) Southern Cal.
(Lucerne vs Joshua Tree record.)

- Forward Directivity
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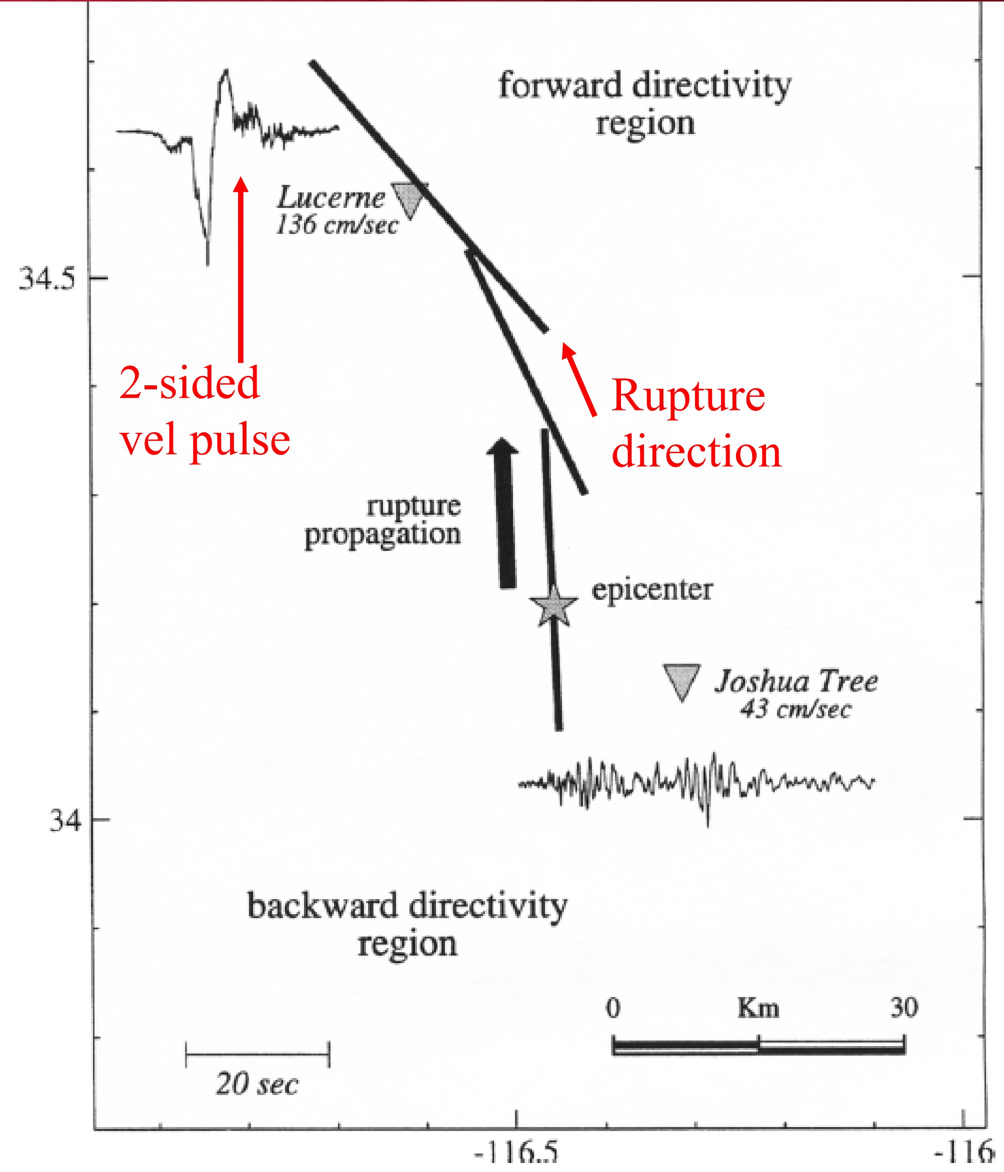


▲ **Figure 3.** Map of the Landers region showing the location of the rupture of the 1992 Landers earthquake (which occurred on three fault segments), the epicenter, and the recording stations at Lucerne and Joshua Tree. The strike normal velocity time histories at Lucerne and Joshua Tree exhibit forward and backward rupture directivity effects respectively.

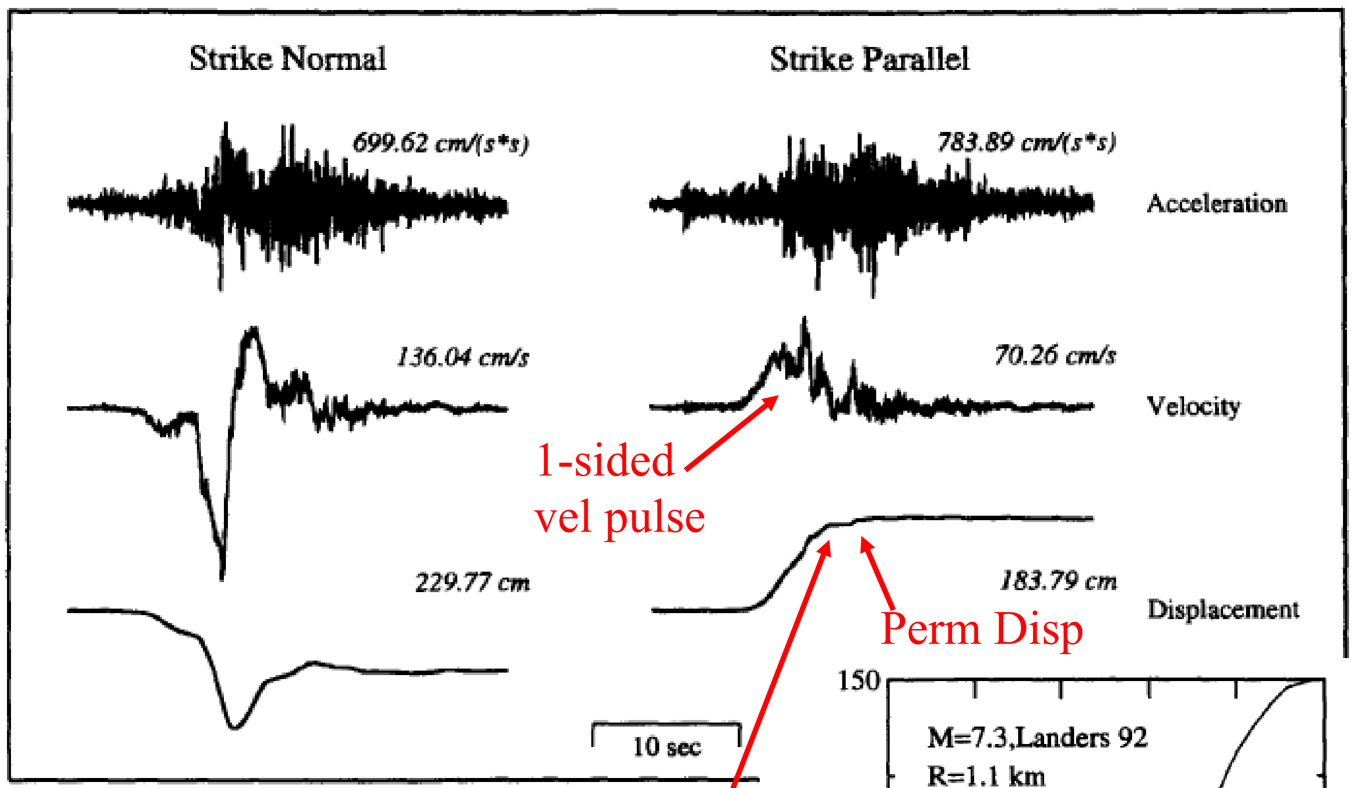
Earthquake Ground Motions

Near Fault Effects

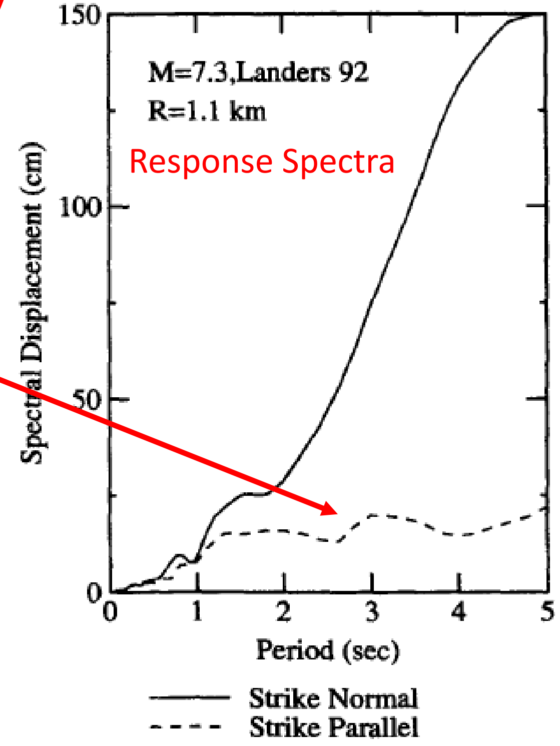
Somerville et al. (1997)

1992 Landers Earthquake (Mw = 7.3) Southern Cal.
(Lucerne vs Joshua Tree record.)

- Fling Step (R< 5 km)
  - Permanent ground fault displacement over a short time
  - Caused by the 1-sided velocity pulse
  - For strike-slip fault, fling step occurs on the fault parallel component



Don't see the permanent displacement in Sd. Remember Sd is relative displacement



▲ **Figure 4.** Top: acceleration, velocity and displacement time histories of the strike-normal and strike-parallel components of horizontal motion recorded at Lucerne during the 1992 Landers earthquake. Bottom: strike-normal and strike-parallel displacement response spectra of the Lucerne record.

Earthquake Ground Motions

Near Fault Effects

Shahi and Baker (2014)

It is not easy to classify a motion as pulse or non-pulse (i.e., containing directivity effects).

Shahi and Baker (2014) use the PGV classify ground motions.
(if PI >0 is pulse)

$$\mathrm{PC} = 0.63 \times (\mathrm{PGV\ ratio}) + 0.777 \times (\mathrm{energy\ ratio}).$$

$$\mathrm{PI} = 9.384(0.76 - \mathrm{PC} - 0.0616\mathrm{PGV})(\mathrm{PC} + 6.914 \times 10^{-4}\mathrm{PGV} - 1.072) - 6.179.$$

Classifying motions as Pulse or non-pulse is important so that ground motion modeling can include directive in the design ground motions.

Table 1
Data for All Fault-Normal Ground Motions in the NGA Database That Are Identified as Pulselike Using the Proposed Classification Procedure

No.	Event	Year	Station	T_p	PGV	M_w*	Distance: Closest†	Distance: Epicentral‡
1	San Fernando	1971	Pacoima Dam (upper left abut)	1.6	116.5	6.6	1.8	11.9
2	Coyote Lake	1979	Gilroy Array #6	1.2	51.5	5.7	3.1	4.4
3	Imperial Valley-06	1979	Aeropuerto Mexicali	2.4	44.3	6.5	0.3	2.5
4	Imperial Valley-06	1979	Agrarias	2.3	54.4	6.5	0.7	2.6
5	Imperial Valley-06	1979	Brawley Airport	4.0	36.1	6.5	10.4	43.2
6	Imperial Valley-06	1979	EC County Center FF	4.5	54.5	6.5	7.3	29.1
7	Imperial Valley-06	1979	EC Meloland Overpass FF	3.3	115.0	6.5	0.1	19.4
8	Imperial Valley-06	1979	El Centro Array #10	4.5	46.9	6.5	6.2	26.3
9	Imperial Valley-06	1979	El Centro Array #11	7.4	41.1	6.5	12.5	29.4
10	Imperial Valley-06	1979	El Centro Array #3	5.2	41.1	6.5	12.9	28.7
11	Imperial Valley-06	1979	El Centro Array #4	4.6	77.9	6.5	7.1	27.1
12	Imperial Valley-06	1979	El Centro Array #5	4.0	91.5	6.5	4.0	27.8
13	Imperial Valley-06	1979	El Centro Array #6	3.8	111.9	6.5	1.4	27.5
14	Imperial Valley-06	1979	El Centro Array #7	4.2	108.8	6.5	0.6	27.6
15	Imperial Valley-06	1979	El Centro Array #8	5.4	48.6	6.5	3.9	28.1
16	Imperial Valley-06	1979	El Centro Differential Array	5.9	59.6	6.5	5.1	27.2
17	Imperial Valley-06	1979	Holtville Post Office	4.8	55.1	6.5	7.7	19.8
18	Mammoth Lakes-06	1980	Long Valley Dam (upper left abut)	1.1	33.1	5.9		14.0
19	Irpinia, Italy-01	1980	Sturno	3.1	41.5	6.9	10.8	30.4
20	Westmorland	1981	Parachute Test Site	3.6	35.8	5.9	16.7	20.5
21	Coalinga-05	1983	Oil City	0.7	41.2	5.8		4.6
22	Coalinga-05	1983	Transmitter Hill	0.9	46.1	5.8		6.0
23	Coalinga-07	1983	Coalinga – 14th & Elm (old CHP)	0.4	36.1	5.2		9.6
24	Morgan Hill	1984	Coyote Lake Dam (southwest abut)	1.0	62.3	6.2	0.5	24.6
25	Morgan Hill	1984	Gilroy Array #6	1.2	35.4	6.2	9.9	36.3
26	Taiwan SMART1(40)	1986	SMART1 C00	1.6	31.2	6.3		68.2
27	Taiwan SMART1(40)	1986	SMART1 M07	1.6	36.1	6.3		67.2
28	N. Palm Springs	1986	North Palm Springs	1.4	73.6	6.1	4.0	10.6
29	San Salvador	1986	Geotech Investigation Center	0.9	62.3	5.8	6.3	7.9
30	Whittier Narrows-01	1987	Downey – company maintenance building	0.8	30.4	6.0	20.8	16.0

Pulse like motion Examples from Baker (2007)

Earthquake Ground Motions

Near Fault Effects

As required by many codes, near fault effects have to be considered for sites within 9.5 miles of the surface projection of an active fault capable of producing a Mw 7 or larger event

or 6.25 miles of the surface projection of an active fault capable of producing a Mw 6 or larger event

EXCEPTIONS:

1. Faults with estimated slip rate along the fault less than 0.04 in. (1 mm) per year shall not be considered.
2. The surface projection shall not include portions of the fault at depths of 6.25 mi (10 km) or greater.

The code does not explicitly account for near fault effects.

Shahi and Baker (2014) provide a period-by-period multiplier for $Sa_{RotD100}/Sa_{RotD50}$ to apply to the response spectra to adjust it from the median to the dominate direction of motion. (Designed for NGA West 2)

Abrahamson (2000) Has additional factors That can be used for Other GMPEs.

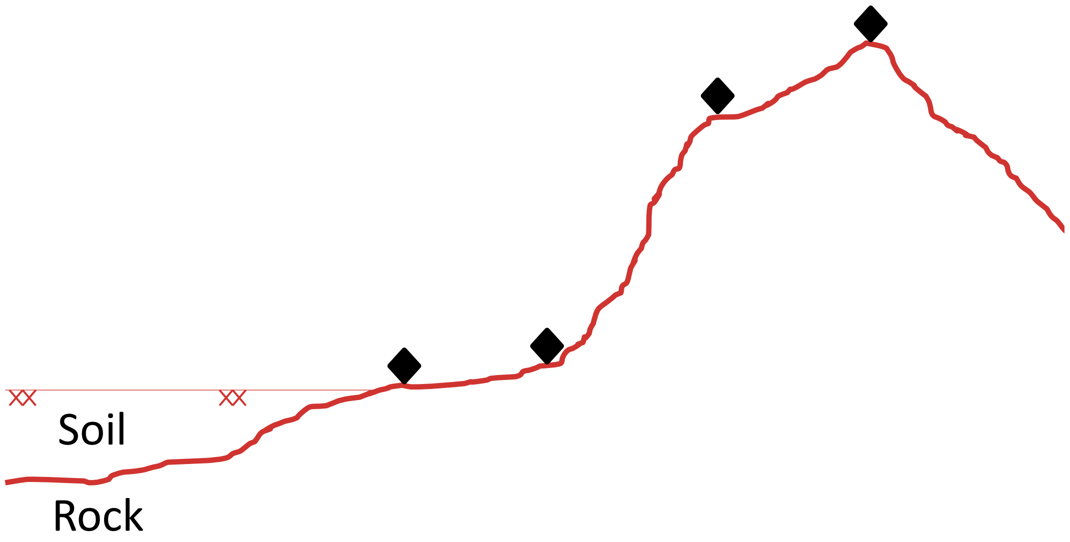
Period (s)	$ln(Sa_{RotD100}/Sa_{RotD50})$	$Sa_{RotD100}/Sa_{RotD50}$	ϕ	τ	σ_{total}
0.01	0.176	1.19	0.08	0.01	0.08
0.02	0.175	1.19	0.08	0.01	0.08
0.03	0.172	1.19	0.08	0.01	0.08
0.05	0.171	1.19	0.08	0.01	0.08
0.075	0.172	1.19	0.08	0.01	0.08
0.1	0.172	1.19	0.08	0.01	0.08
0.15	0.182	1.20	0.08	0.01	0.08
0.2	0.187	1.21	0.08	0.01	0.08
0.25	0.196	1.22	0.08	0.01	0.08
0.3	0.198	1.22	0.08	0.01	0.08
0.4	0.206	1.23	0.08	0.01	0.08
0.5	0.206	1.23	0.09	0.01	0.09
0.75	0.213	1.24	0.08	0.01	0.09
1	0.216	1.24	0.08	0.01	0.08
1.5	0.217	1.24	0.08	0.01	0.08
2	0.218	1.24	0.08	0.01	0.08
3	0.221	1.25	0.08	0.01	0.08
4	0.231	1.26	0.08	0.01	0.08
5	0.235	1.26	0.08	0.02	0.08
7.5	0.251	1.28	0.08	0.02	0.08
10	0.258	1.29	0.07	0.03	0.08

Earthquake Ground Motions

Topographic Effects

How does Topography influence earthquake ground motions?

Would all of these "Rock Sites" experience the same GM during an earthquake, all other things being equal?



Civita di Bagnoregio, Italy

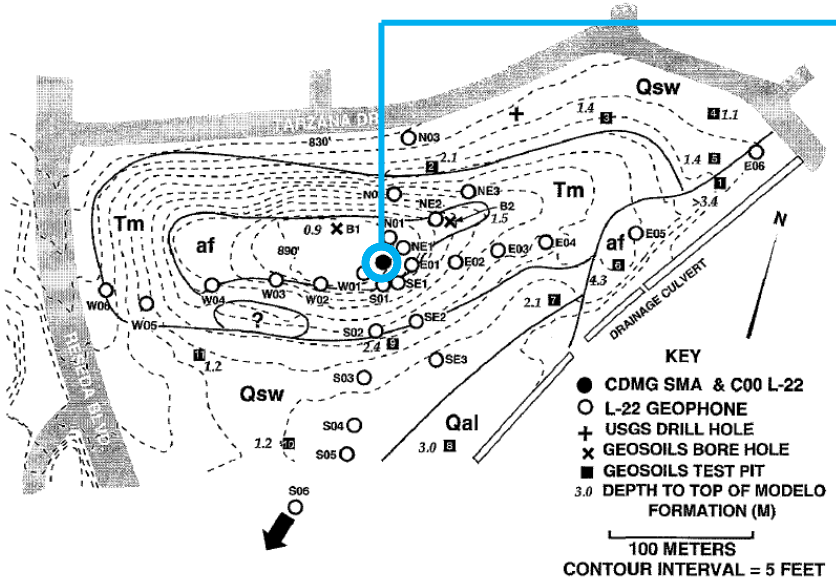
Earthquake Ground Motions

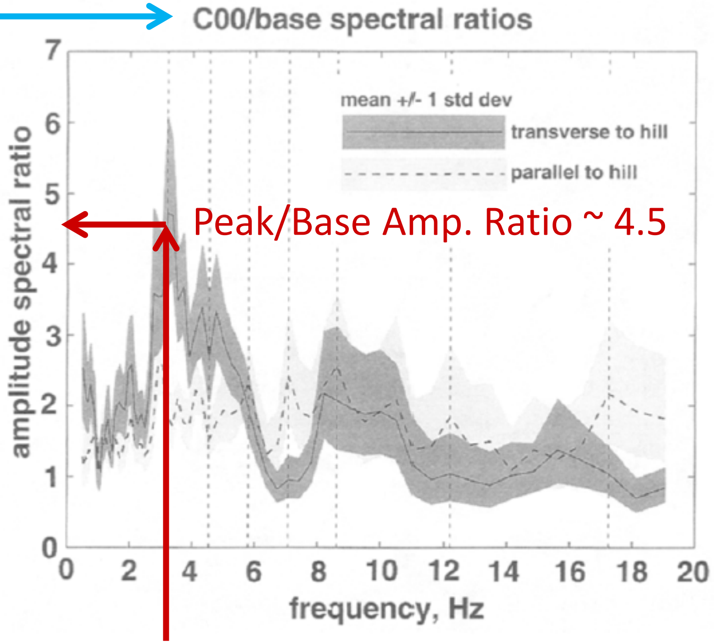
Topographic Effects

1994 Northridge EQ: Tarzana Station

PGA = 1.78 g “one of the highest accelerations ever recorded” Spudich et al. 1996

21, 3-component geophones deployed to record aftershocks and investigate topographic amplification





Peak/Base Amp. Ratio ~ 4.5

Hill Dimensions
15-m high
500-m long
130-m wide

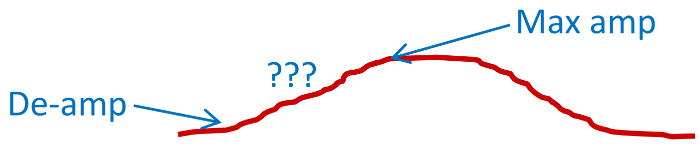
Transverse Resonant Freq. of Hill ~ 3.2 Hz

16 aftershocks analyzed

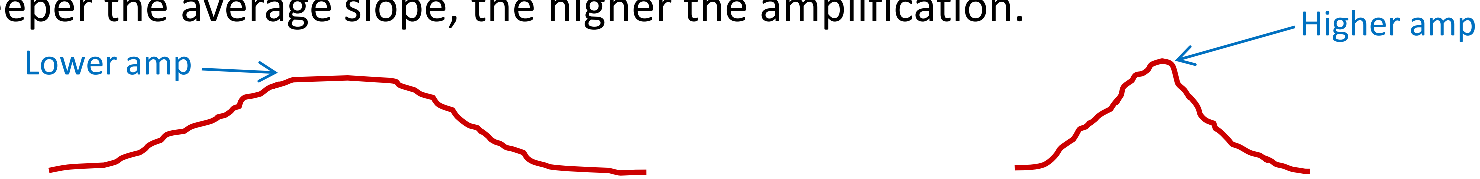
Earthquake Ground Motions

Topographic Effects

(1) The maximum amplification attributed to topography occurs at, or near, the peak of the ridge, the maximum deamplification occurs near the toe (base) of the feature, and irregular amplification-deamplification patterns are observed in between.



(2) The observed, or computed, amplification is related to the “sharpness” of the topography: the steeper the average slope, the higher the amplification.

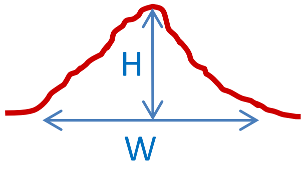


(3) The amplifications are highly frequency-dependent and seem to occur at wavelengths (λ) comparable to a characteristic length of the feature, such as width and/or height (Paolucci 2002, Ashford et al. 1997).

$V = f * \lambda$

or

$f = V / \lambda$



$\lambda \sim W$

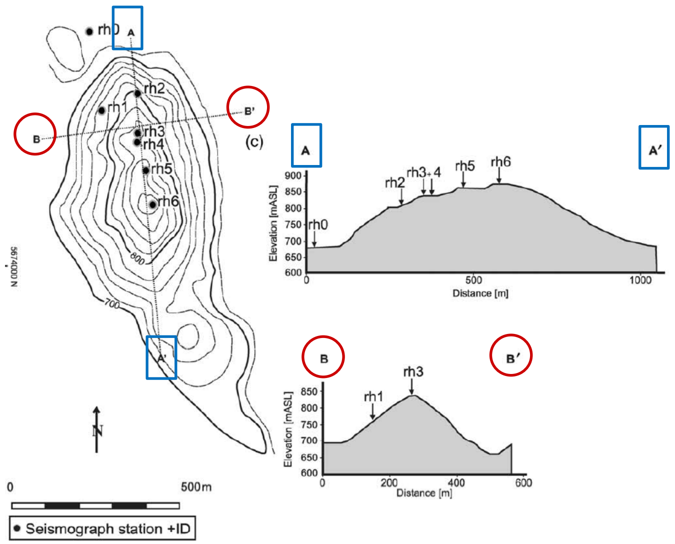
or

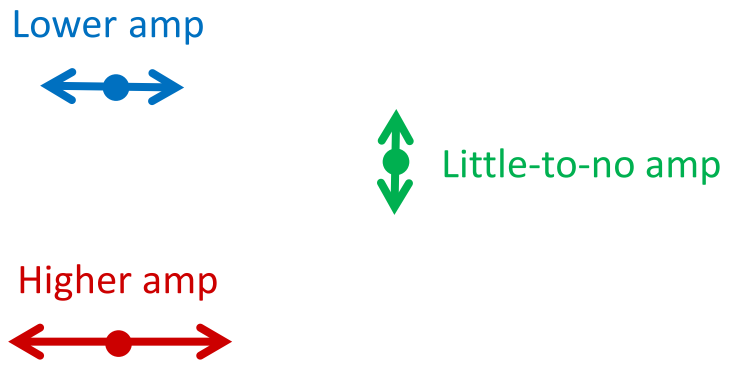
$\lambda \sim 5*H$

Earthquake Ground Motions

Topographic Effects

(4) Amplifications of particle motion in the direction perpendicular to the direction of elongation of the ridge seem to be larger than the motions parallel to the elongation direction of the ridge.





(5) The vertical direction of particle motion seems to be affected far less, if any, by topographic amplifications.

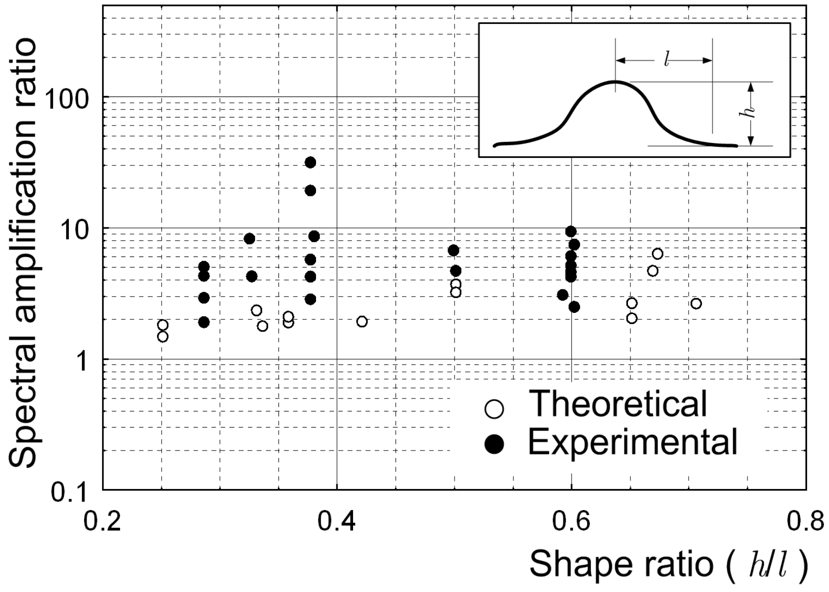
Earthquake Ground Motions

Topographic Effects

(6) Amplification factors determined from field observations can be significantly higher than those determined by numerical simulations.

- **Experimental Field Studies:**
  Topographic amplification factors ranging from 3 – 6 are common (e.g., Spudich et al. 1996; Massa et al. 2010; Hough et al. 2011) with some studies indicating values of 10-plus (e.g., Beuch et al. 2010)

- **Numerical Simulations:**
  Qualitative agreement exists between experimental data and 2D and 3D numerical simulations . However, numerical simulations rarely predict topographic amplification factors greater than 3, with common values less than 2 (e.g., Paolucci 2002; Papadimitriou 2011)



from D. Assimaki (after Geli et al. 1988)

Earthquake Ground Motions

Topographic Effects

Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects Annex A (Informative): Topographic amplification factors (S_T)

This is not a good way of accounting for topographic amplification since the amplification is under-estimated in the hill resonant range and over-estimated everywhere else.

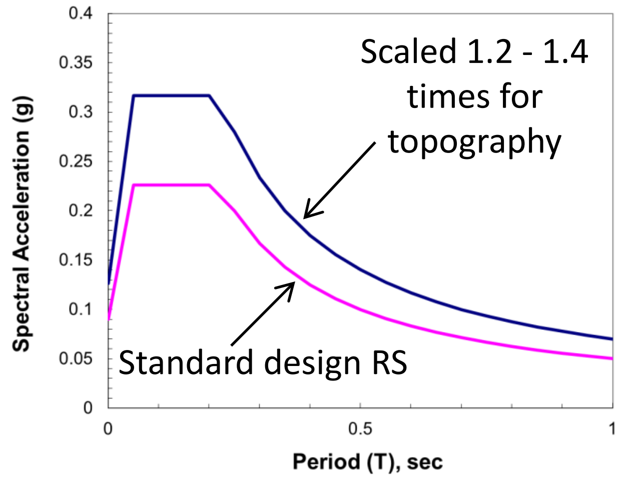
- For topography with H > 30 m… <u>amplification factors range from 1.2 – 1.4</u>

A.2 For average slope angles of less than about 15° the topography effects may be neglected, while a specific study is recommended in the case of strongly irregular local topography. For greater angles the following guidelines are applicable.

a) *Isolated cliffs and slopes*. A value $S_T \geq 1{,}2$ should be used for sites near the top edge;

b) *Ridges with crest width significantly less than the base width*. A value $S_T \geq 1{,}4$ should be used near the top of the slopes for average slope angles greater then 30° and a value $S_T \geq 1{,}2$ should be used for smaller slope angles;

- Considered independent of fundamental period of vibration
- A constant scaling factor to the elastic design response spectrum



Earthquake Ground Motions

Topographic Effects

My recommendations:

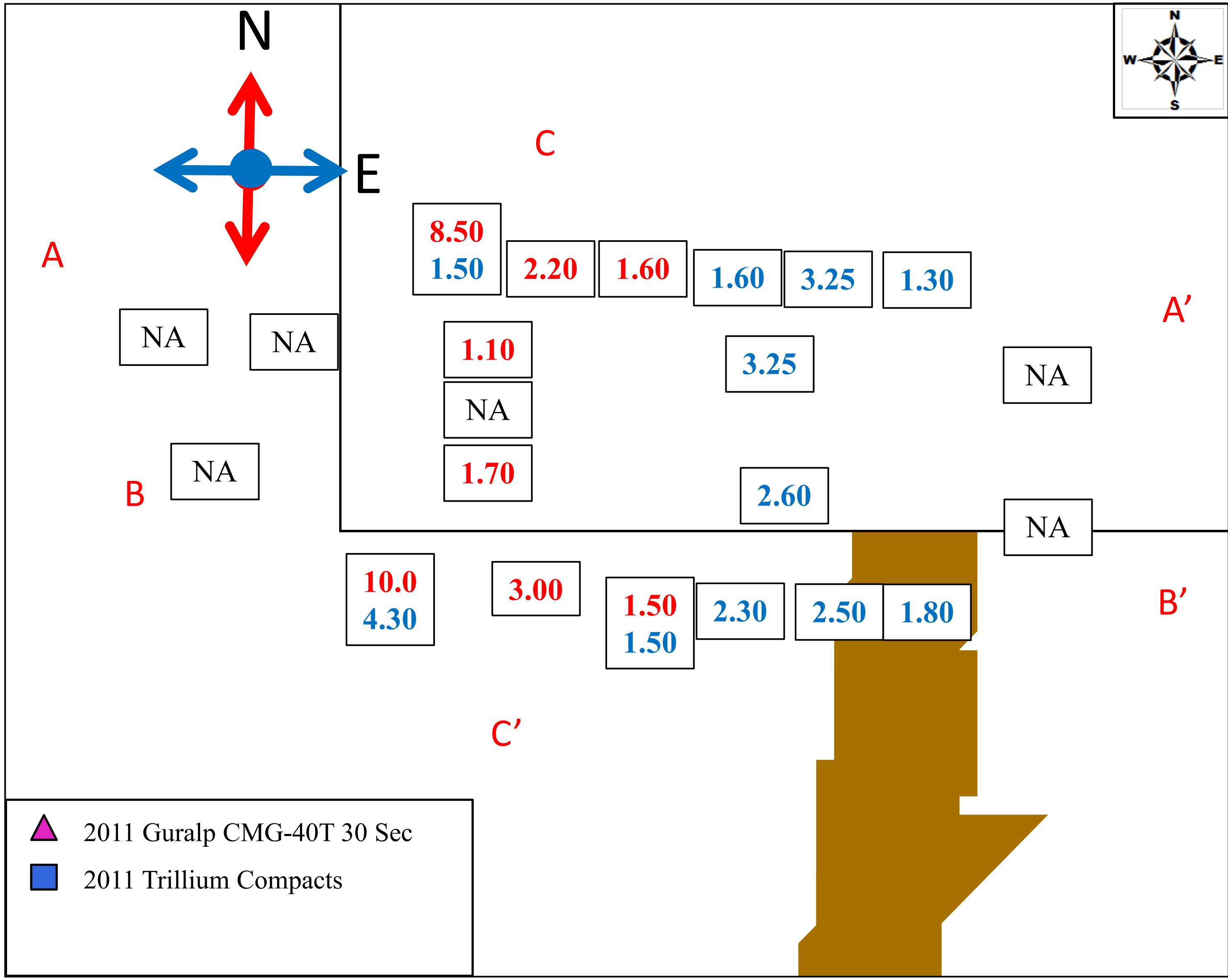
Use the Paolucci 2002 approach to estimate the topographic amplification frequency range.

Frequency = (0.7 to 1.0) (Vs_{avg}/Length) for ridge features.

Can also use Ashford et al. (1997) estimate

$f_{t0} = Vs_{avg}/5.0*\text{Height}$

Amplifications of 2.5-3.25 times the flat ground response are typical, but isolated or peninsula type features can have amplification of 10 times.



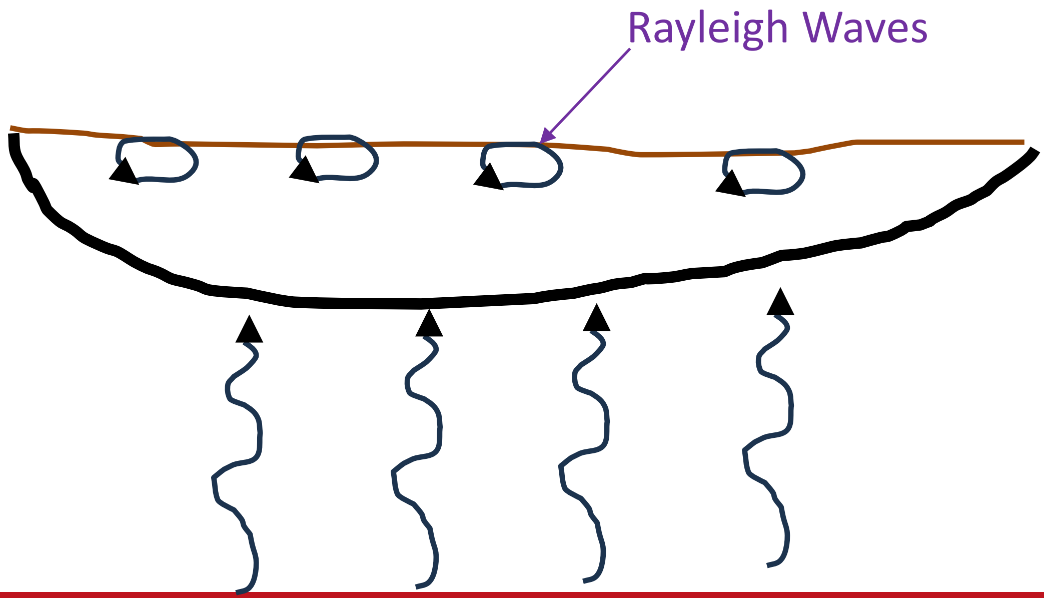
Earthquake Ground Motions

Basin Effects

Seismic waves (Rayleigh waves) can be trapped in the basin and therefore, longer duration and higher ground motions (constructive interference) are observed

Significant amplifications can occur near the edge of the basin as Rayleigh wave strike and bounce off the edge of the basin (i.e., impedance difference)

We still don't have a good enough understanding to capture basin effects in edge and deep basins, but do ok with shallow basins. (Mostly taken into effect with GMPE via Z1.0 and Z2.5 terms along with Vs30 terms).



Questions?