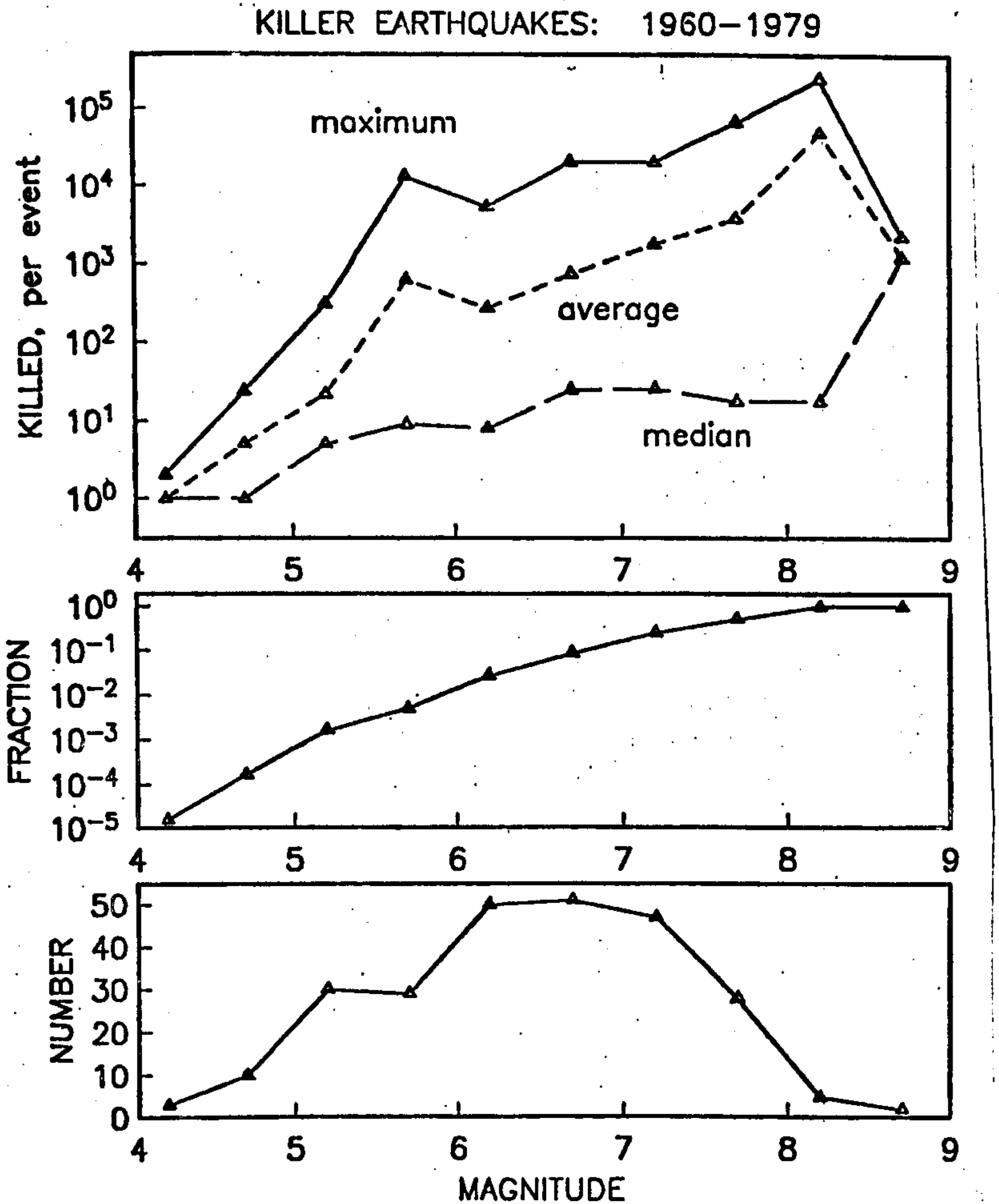
Strong-motion measurements and ground-motion parameters

Lecture 2

Strong-motion measurements and ground-motion parameters

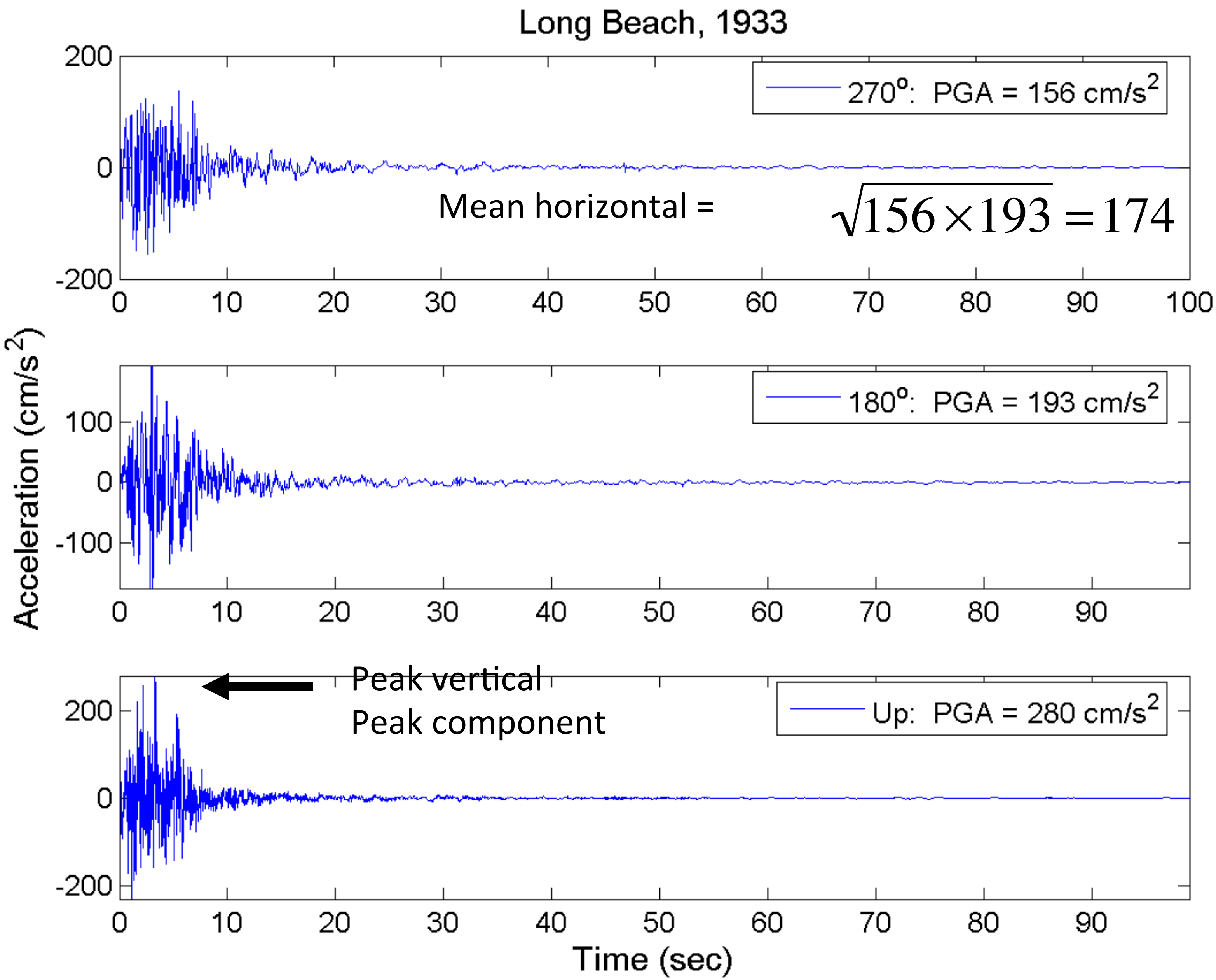
1. Historical development
2. Networks
3. Ground-motion parameters
4. How size of earthquake matters ?
5. Maximum ground-motion
6. Normal and log-normal distributions



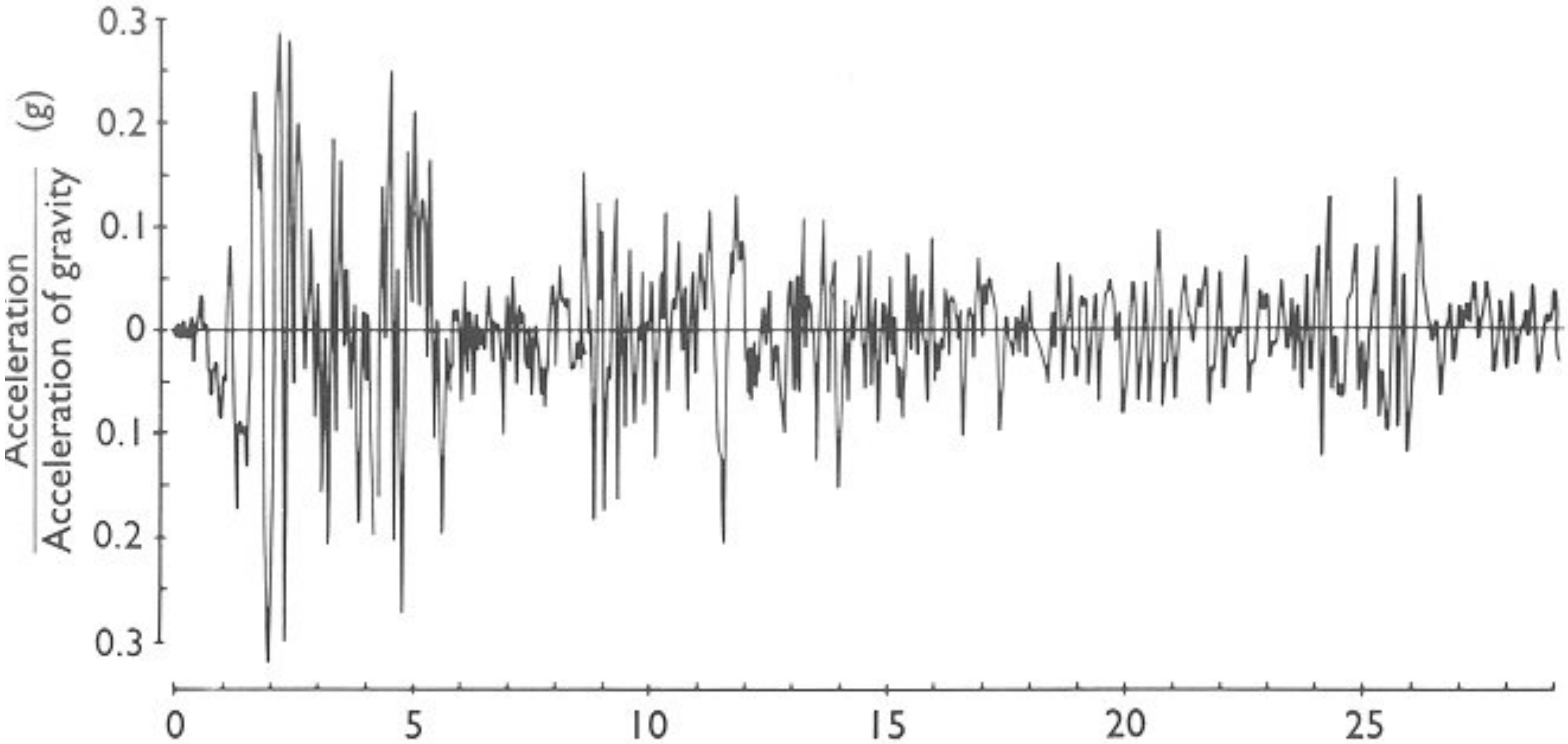
What size earthquakes concern the strong motion seismologist and the earthquake engineer?

Courtesy of J. Anderson

First significant record: March 10, 1933. Mw=6.4



Strong-motion stations are recording ground-motion close to earthquakes without saturation



The famous El Centro record of ground acceleration in the 1940 earthquake in southern California.

Observations

- Most important sources of strong motion data
  - COSMOS (http://www.cosmos-eq.org/)
  - Pacific Earthquake Engineering Research Center (http://peer.berkeley.edu/nga/)
  - Japan K-Net and KiK-Net (http://www.k-net.bosai.go.jp/; http://www.kik.bosai.go.jp/)

Example of high quality databases recently used for Ground-Motion prediction (Share, FP7 project)

- ITACA (Italy) 1165 records (3 components) from 202 events
- NGA (US, Taiwan) 3551 records (3 components) from 173 worldwide events)
- TNSMD (Turkey) 4607 records (3 components) from 2996 events occured in and around Turkey (between 1976 and 2007). 1679 records from 745 events are selected.
- ESMD: 462 records (3 components) from 110 events (major earthquakes occurred in and around Europe between 1973 and 2003) obatined from the Volume 2 CD-Rom (Ambraseys et al., 2004).
- KIK-Net (Japan) 4704 records (6 components for each recording: 3 surface level and 3 below surface) from 596 events occurred in Japan (between 1998 and 2004).
- Cauzzi and Faccioli : 1163 records (2 horizontal components) from 60 worldwide events (mainly from the USA, Italy, Iceland, Turkey and Japan).

Courtesy of Sinan Akkar

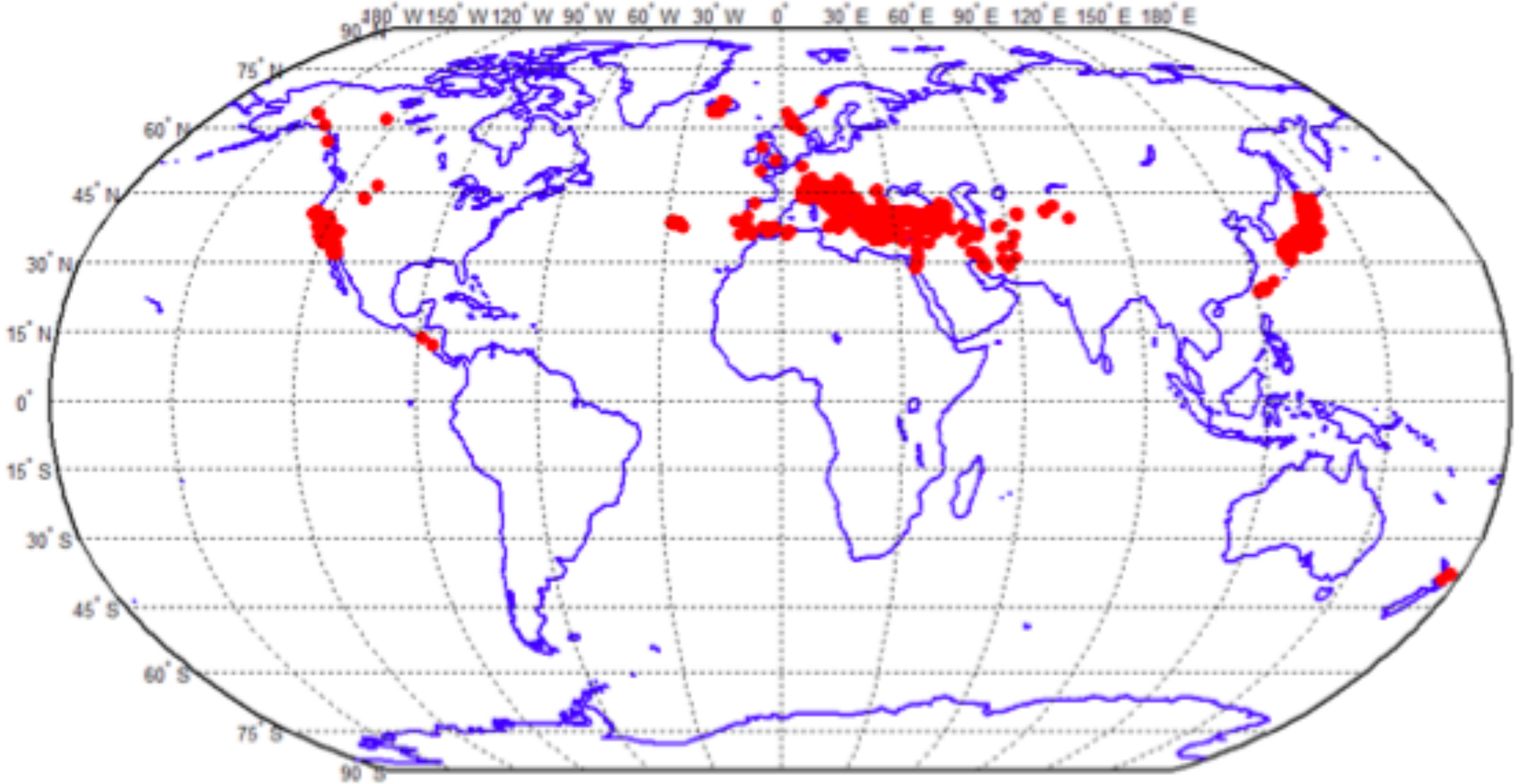


Figure 1. Epicenter locations of the earthquakes presented in the unified databank

Yenier et al., 2010

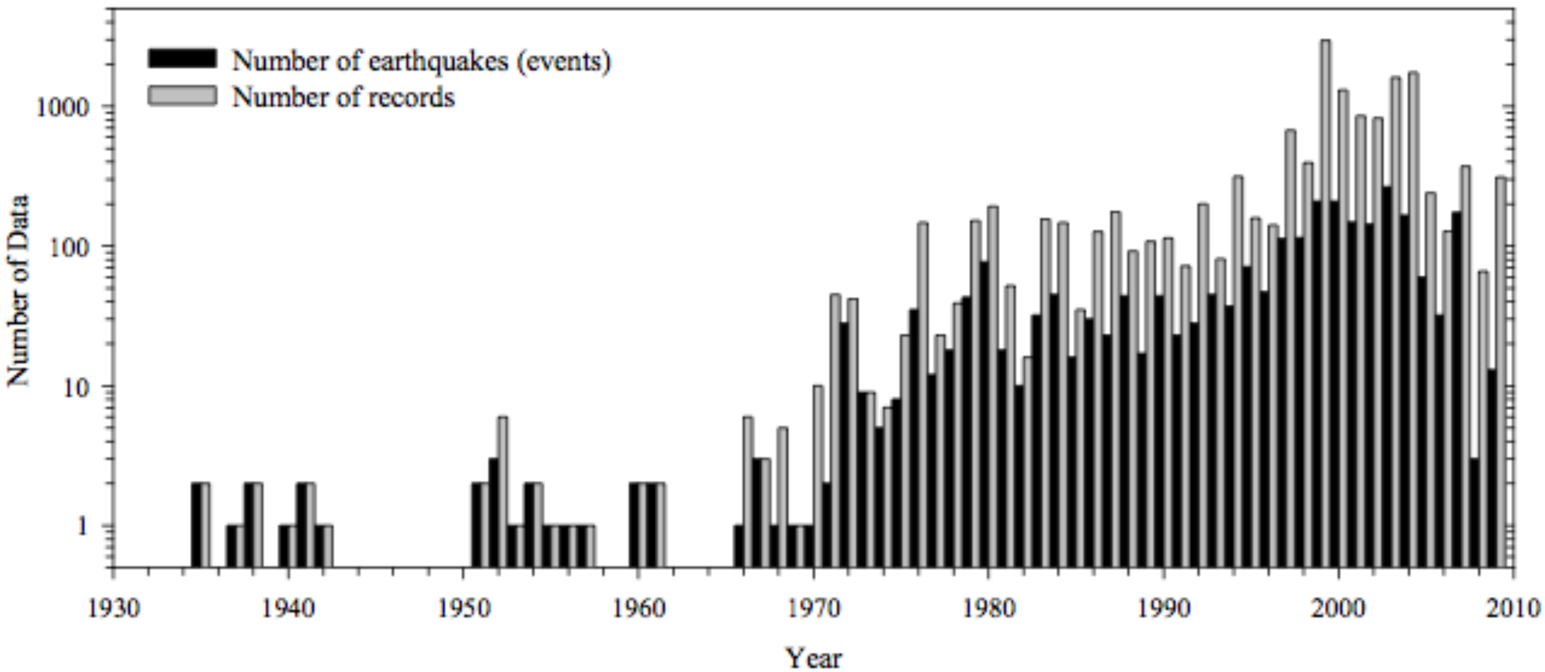
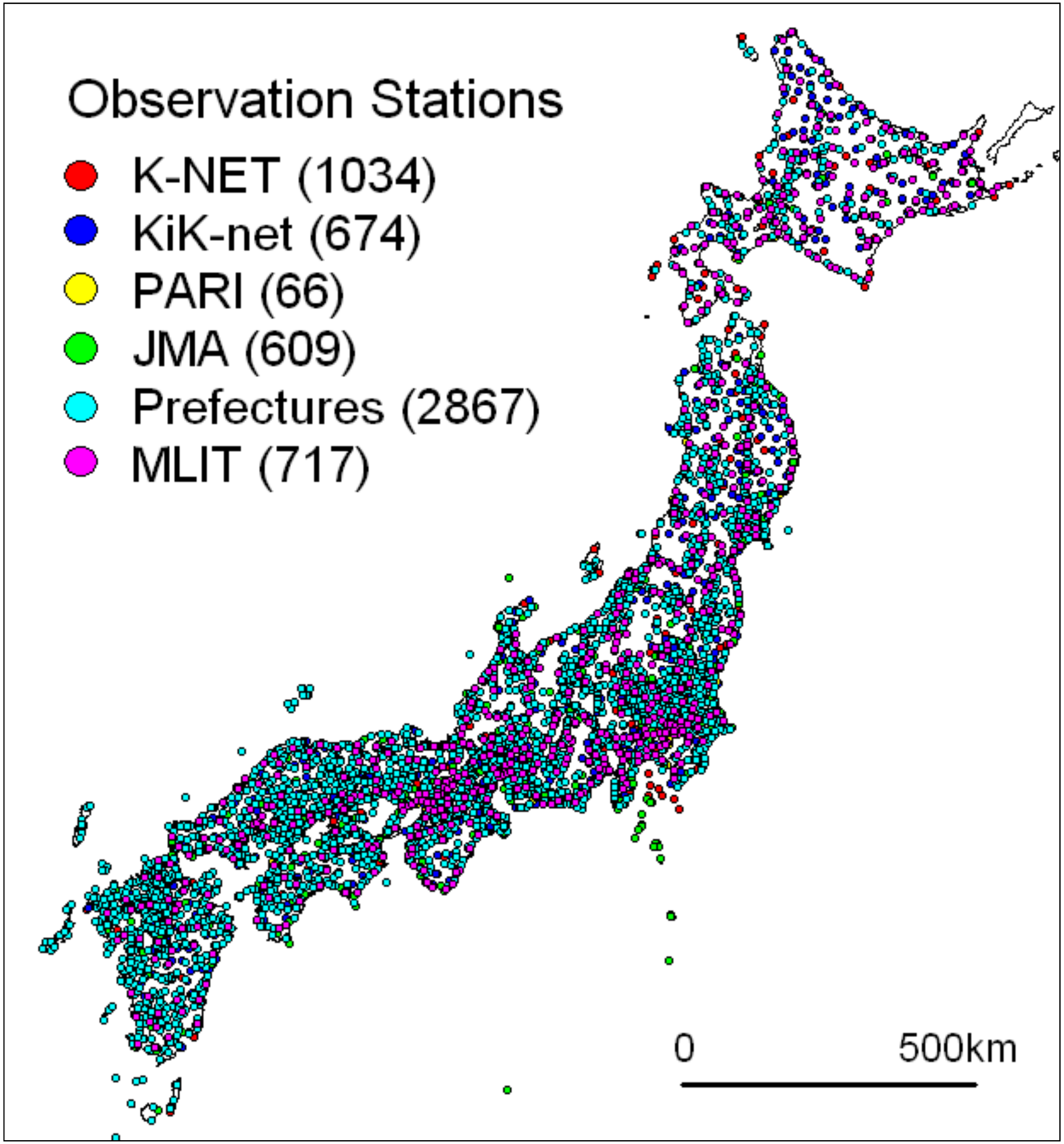


Figure 2. Yearly basis histogram of the earthquakes and ground-motion records existing in the integrated databank. Note that vertical axis is presented in log-scale for a better visual inspection.

Yenier et al., 2010

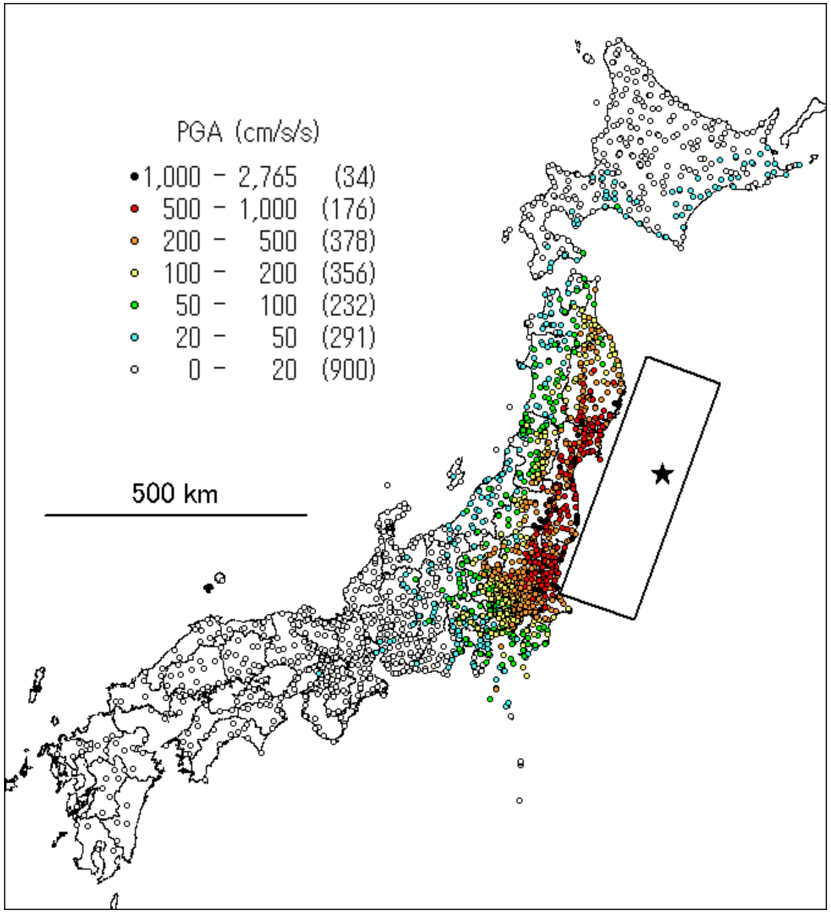
Nation-wide Strong Motion Networks in Japan



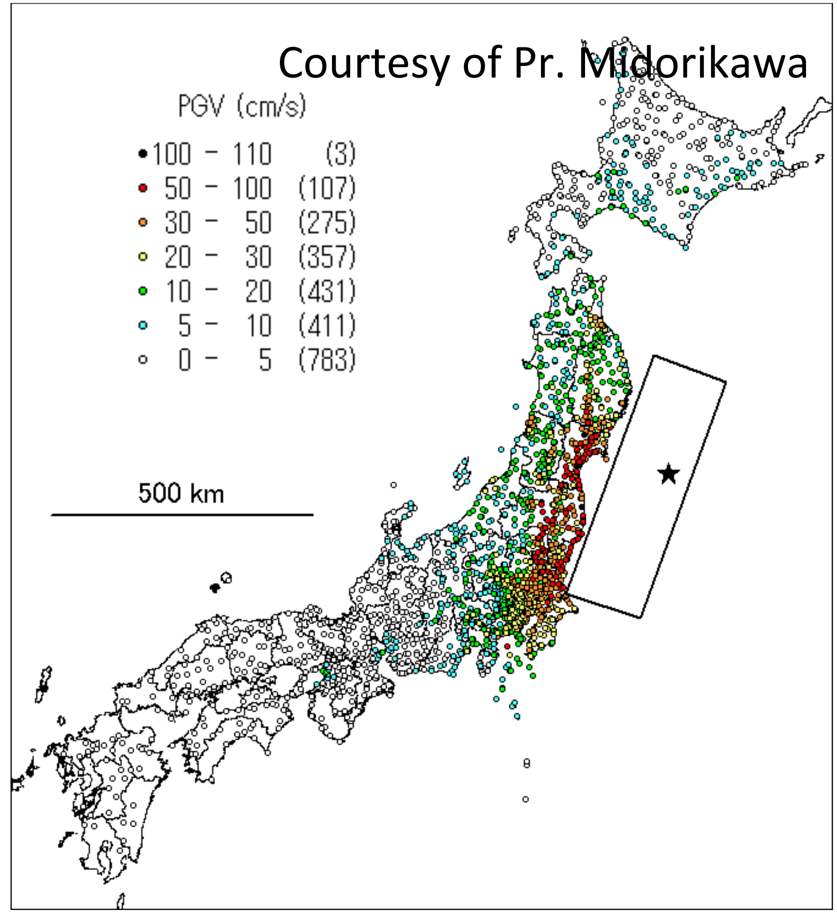
Courtesy of
Pr. Midorikawa

We collected strong motion records on ground in the 2011 Tohoku earthquake from nation wide networks;

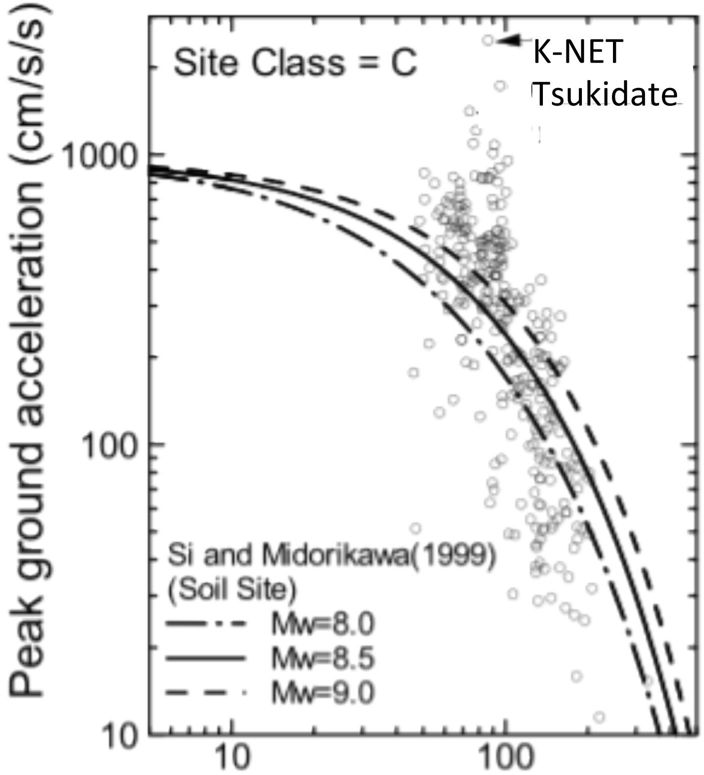
Total 2367 (1223 from K-NET & KiK-net, 1144 from JMA, Prefectures and others)

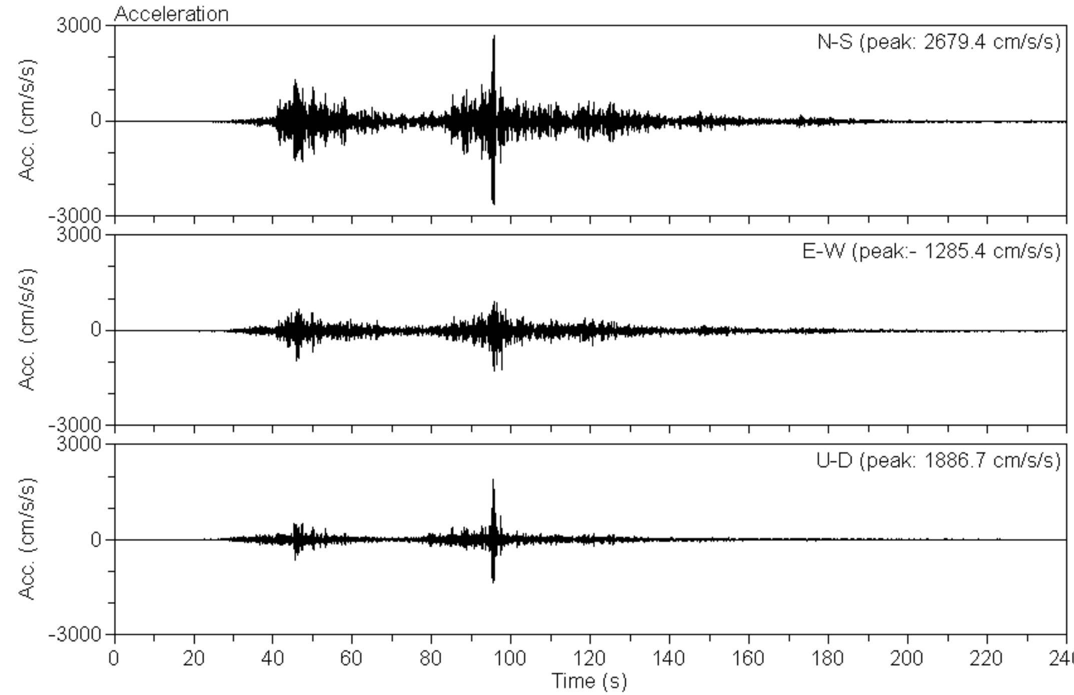


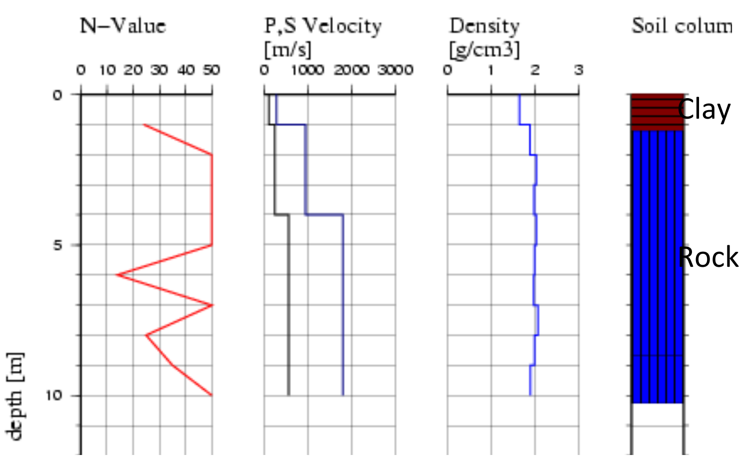
The peak horizontal accelerations higher than 500 cm/s² are observed at 210 sites and accelerations higher than 1000 cm/s² are at 34 sites, respectively.



The peak horizontal velocities higher than 50 cm/s are observed at 110 sites and velocities higher than 100 cm/s are at 3 sites, respectively.





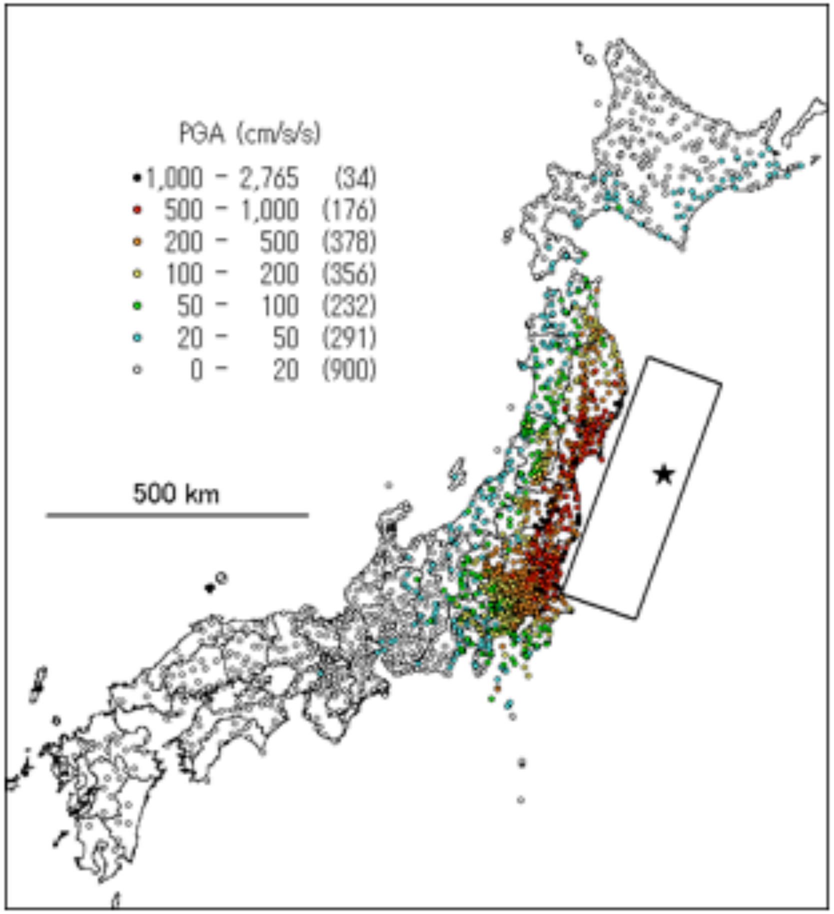


Soil Profile at K-NET Tsukidate

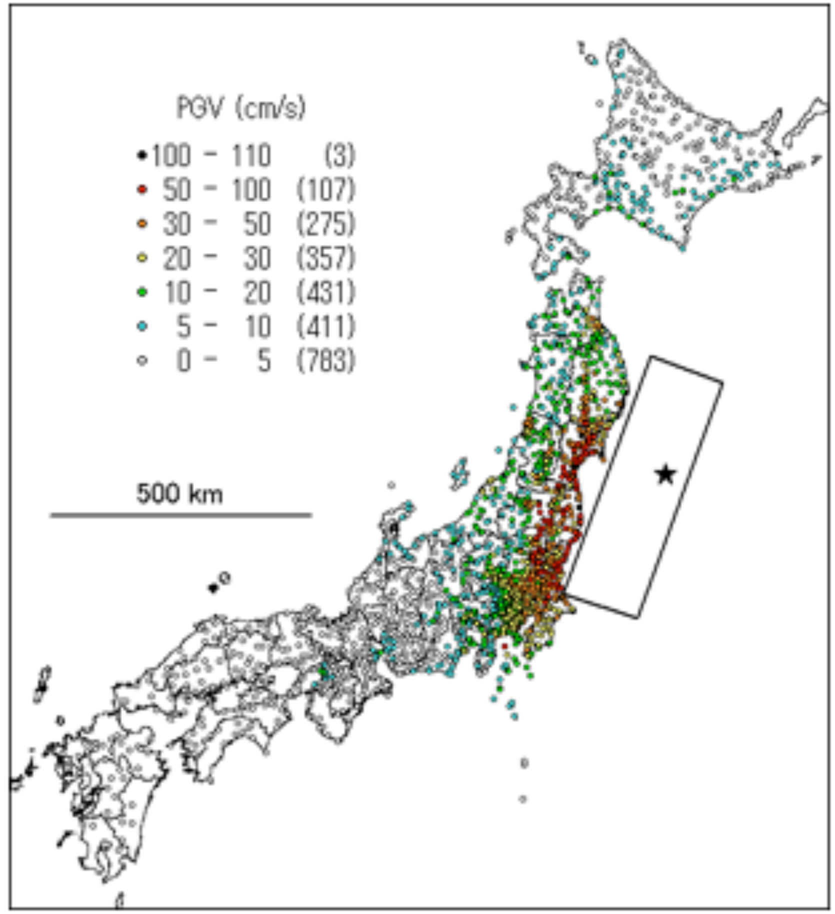
Courtesy of Pr. Midorikawa

We collected strong motion records on ground in the 2011 Tohoku earthquake from nation-wide networks;

Total 2367 (1223 from K-NET & KiK-net, 1144 from JMA, Prefectures and others)



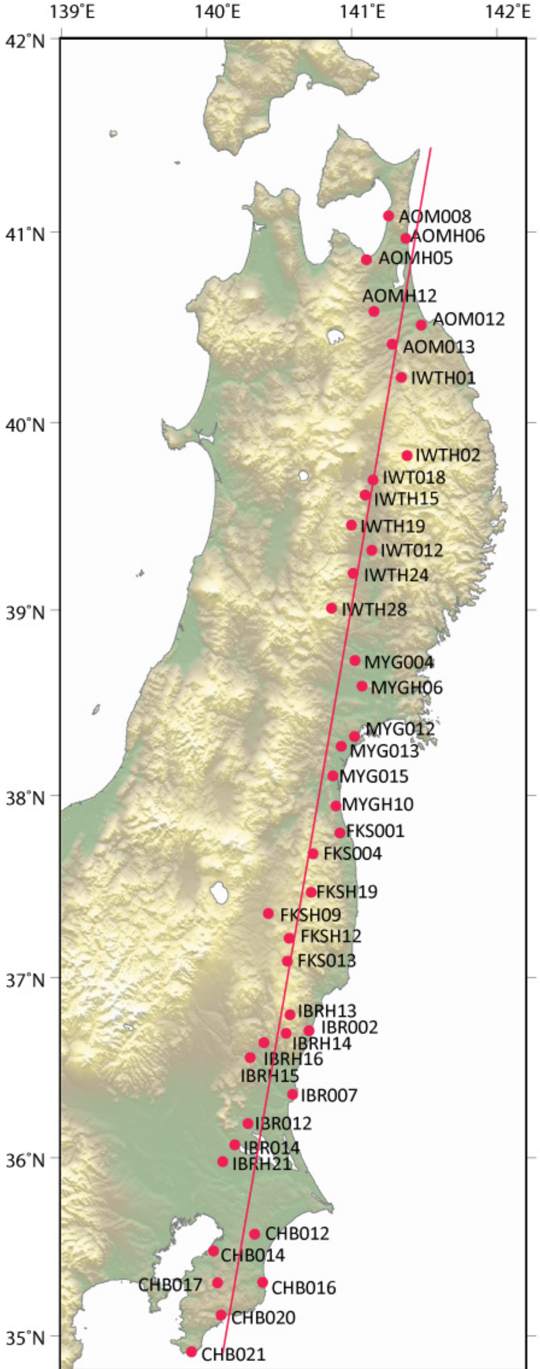
The peak horizontal accelerations higher than 500 cm/s^2 are observed at 210 sites and accelerations higher than 1000 cm/s^2 are at 34 sites, respectively.

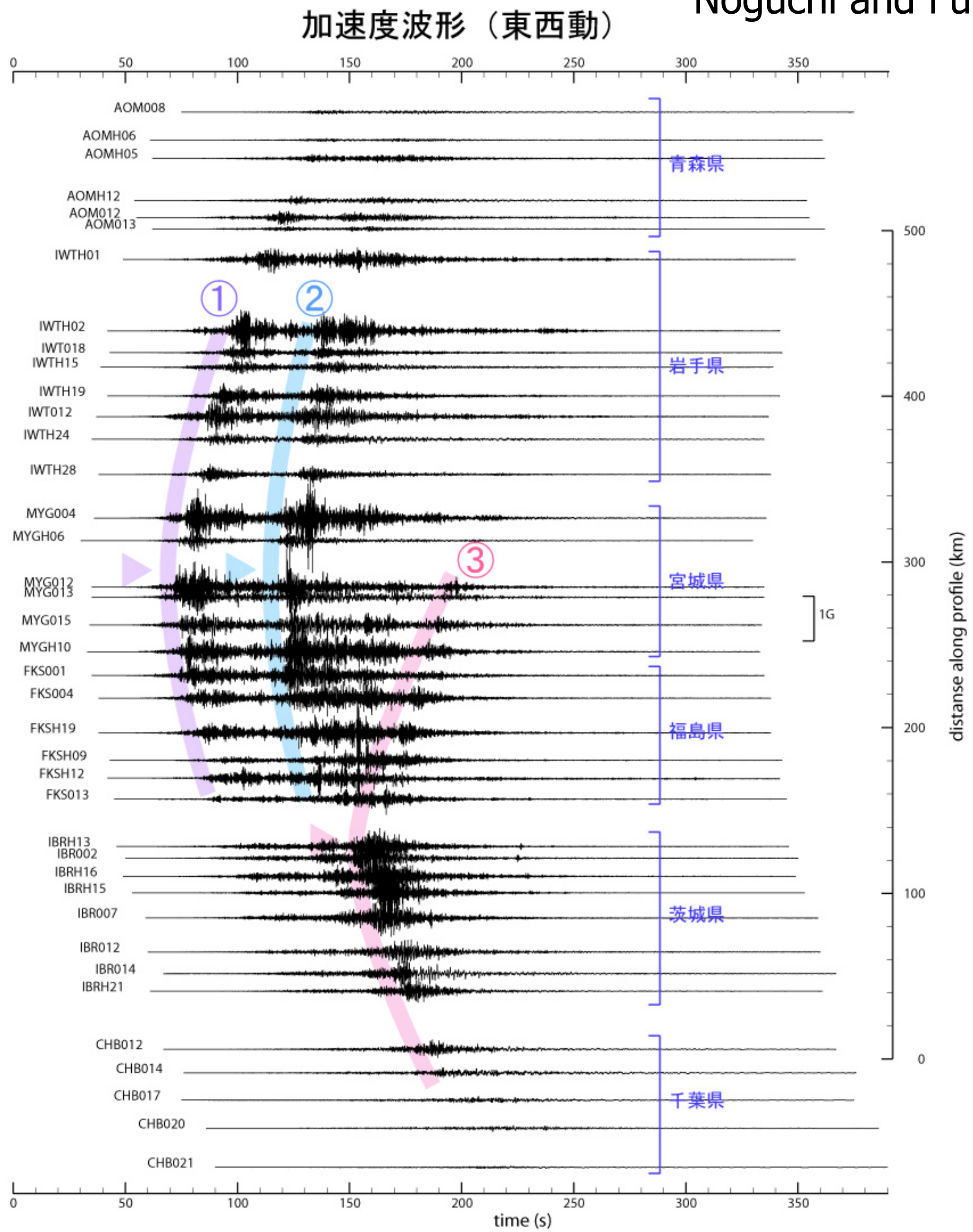


The peak horizontal velocities higher than 50 cm/s are observed at 110 sites and velocities higher than 100 cm/s are at 3 sites, respectively.

K-NET/KiK-net acceleration (EW) for the 2011 Tohoku eq.

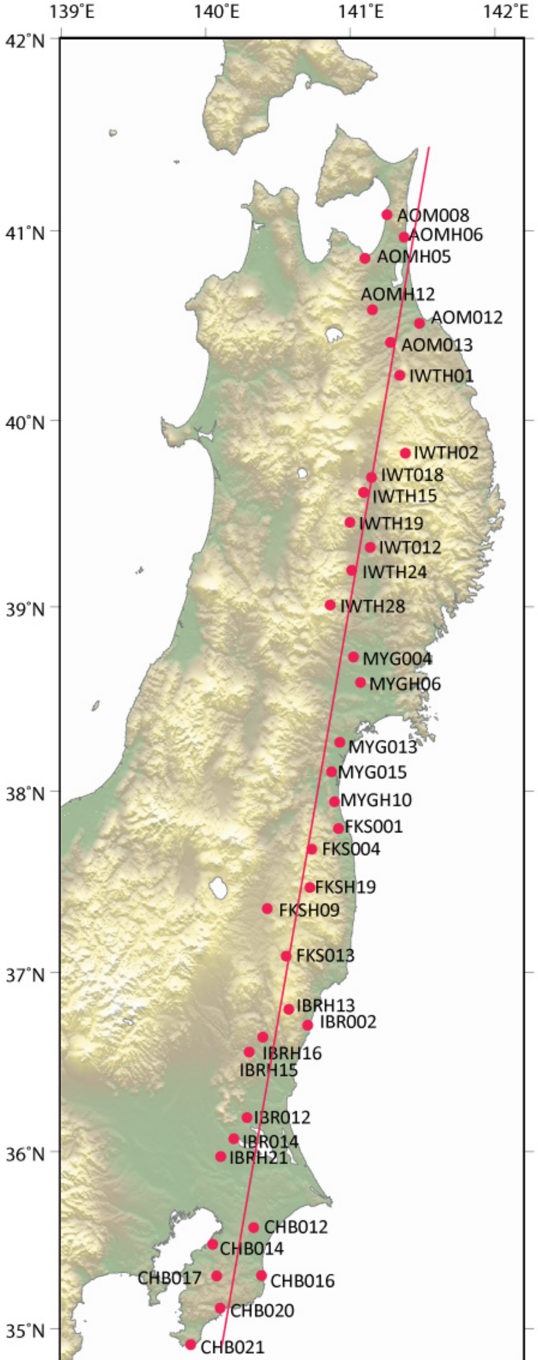
Noguchi and Furumura (2011)

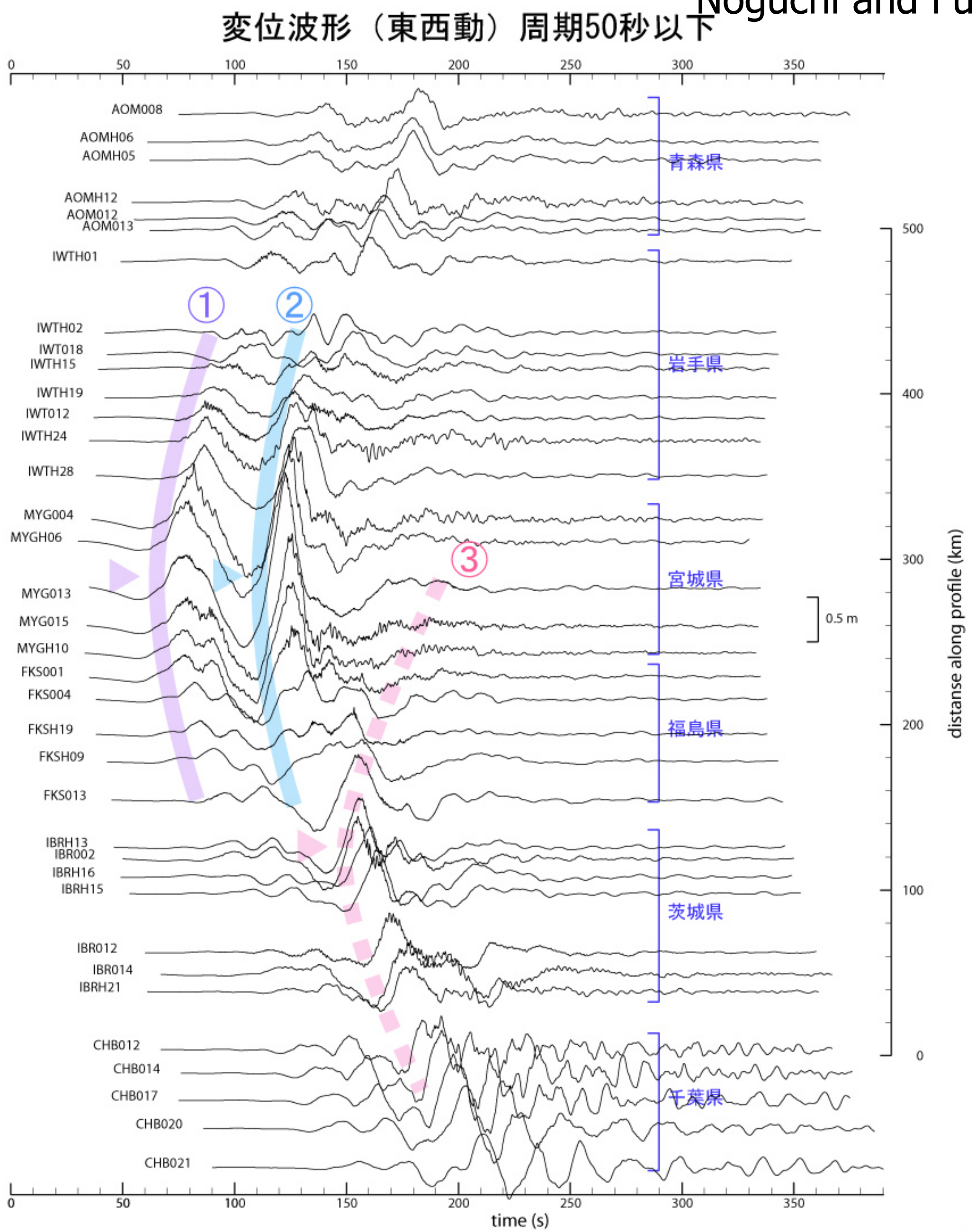




K-NET/KiK-net displacement (EW) for the 2011 Tohoku eq.

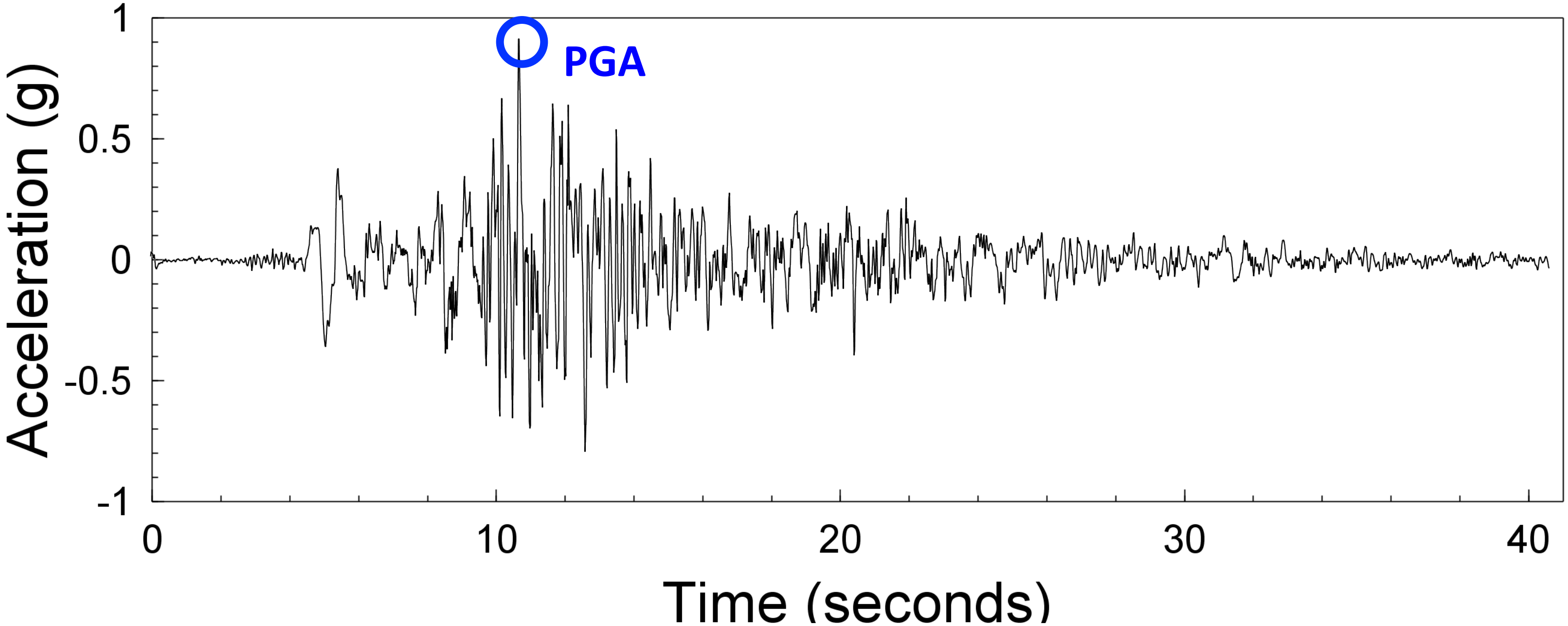
Noguchi and Furumura (2011)





Ground-motion parameters

- PGA
- PGV
- Duration
- Fourier spectrum
- Response spectrum



PGA
1
0.5
0
-0.5
-1
Acceleration (g)
0
10
20
30
40
Time (seconds)

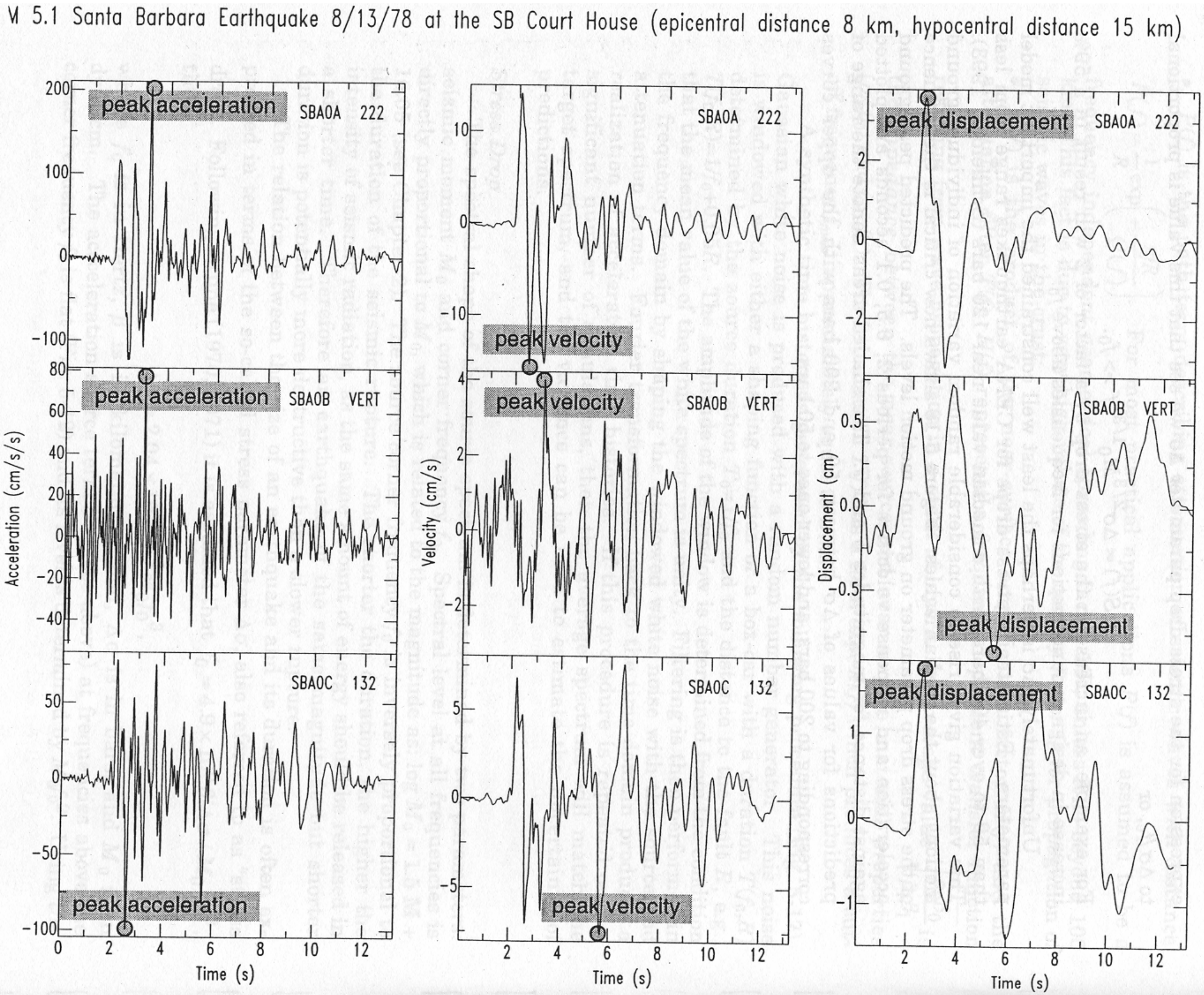
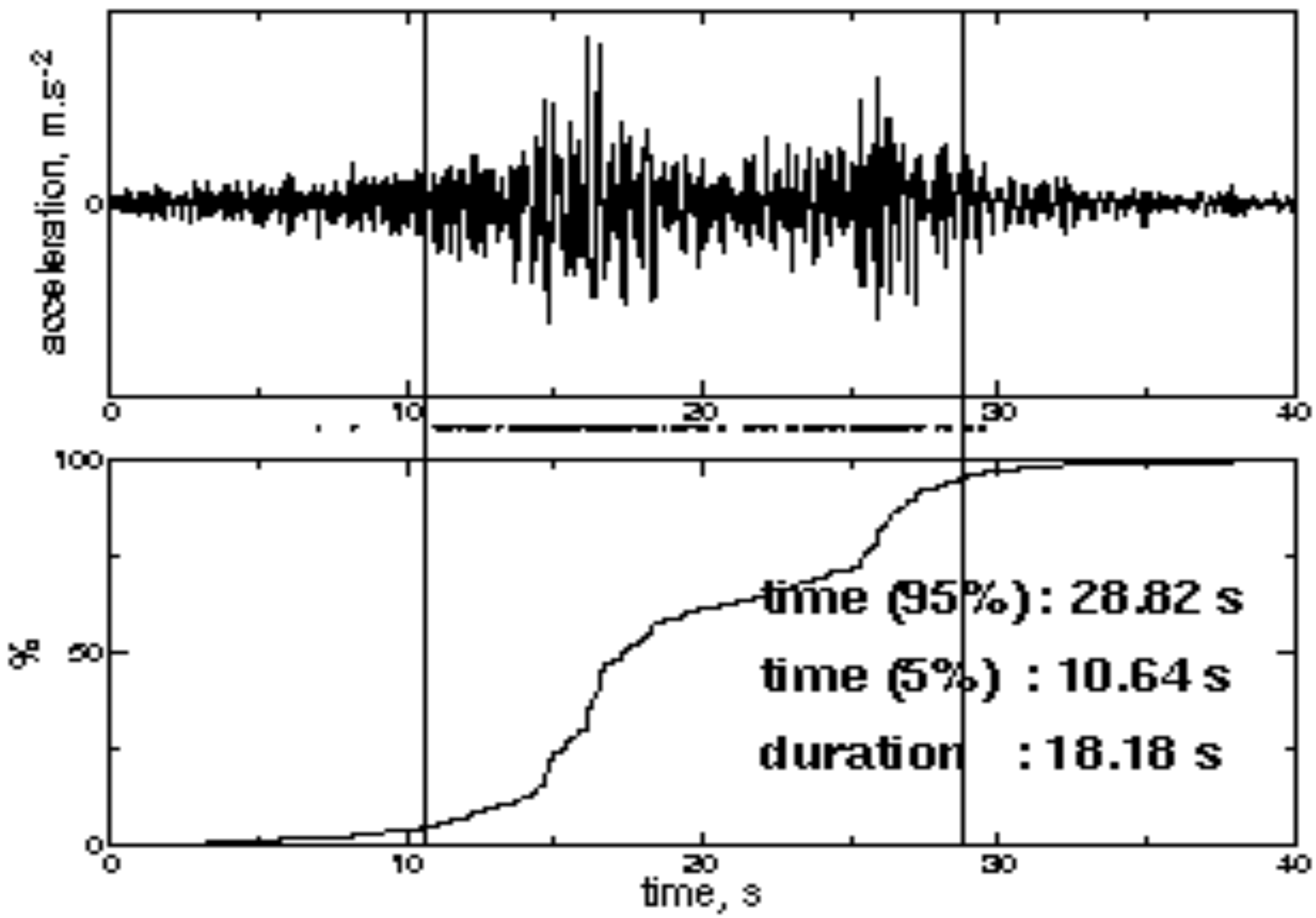


Figure 5-1. Peak characteristics of ground acceleration, velocity and displacement

Source : Archuleta et al., 1997 (gauche), Kramer, 1997 (droite)

Duration : definition 1



Source : Kramer, 1997

Duration : definition 2

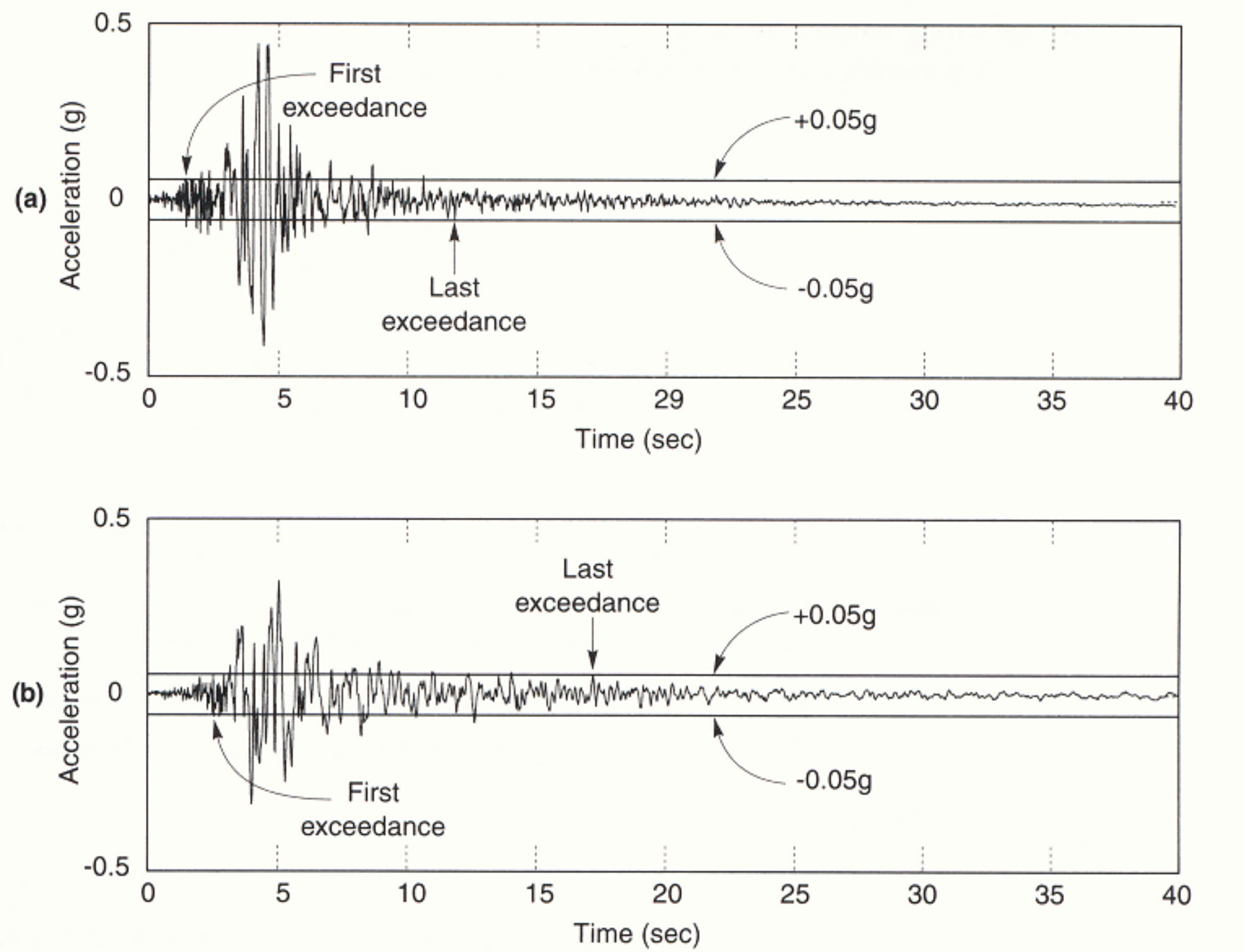


Figure E3.5

Source : Kramer, 1997

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

Magnitude	Duration (sec)	
	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

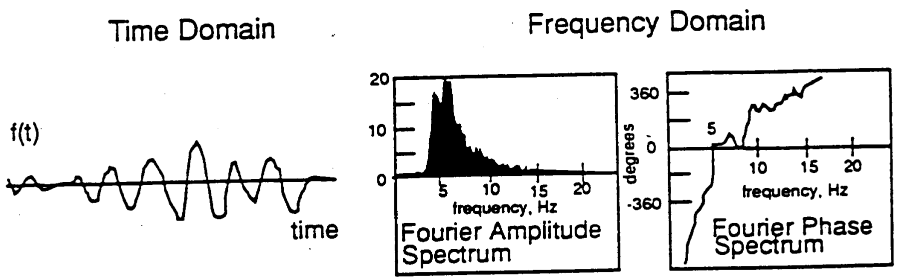
Source: Chang and Krinitzsky (1977).

Fourier spectrum: Definition

- For any time series g(t), the Fourier spectrum is:

$$G(\omega) = \int_{-\infty}^{\infty} g(t)\exp\left(i\omega\, t\right)dt$$

Fourier transform and sampling



A signal that is a function of time, as shown on the left, may be equivalently represented by its Fourier spectrum, as shown on the right. The amplitude and phase spectra are both needed to provide the complete time series.

$$\frac{1}{2\pi}\sum |A(\omega)| e^{i[\omega t + \phi(\omega)]}\Delta\omega$$

=

f(t)

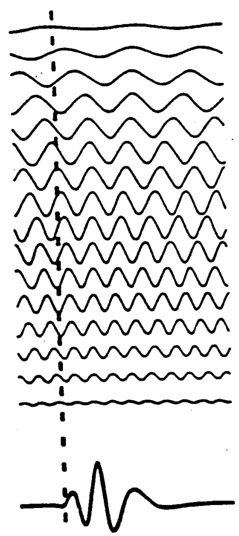
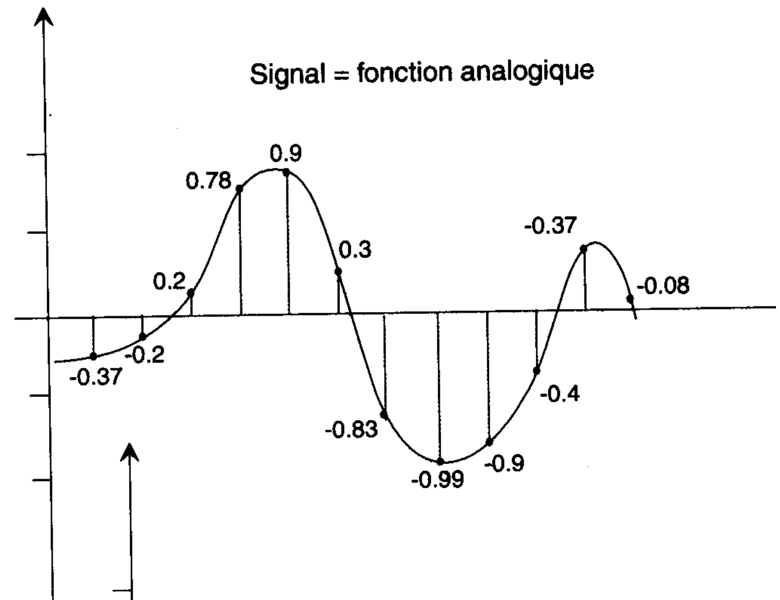
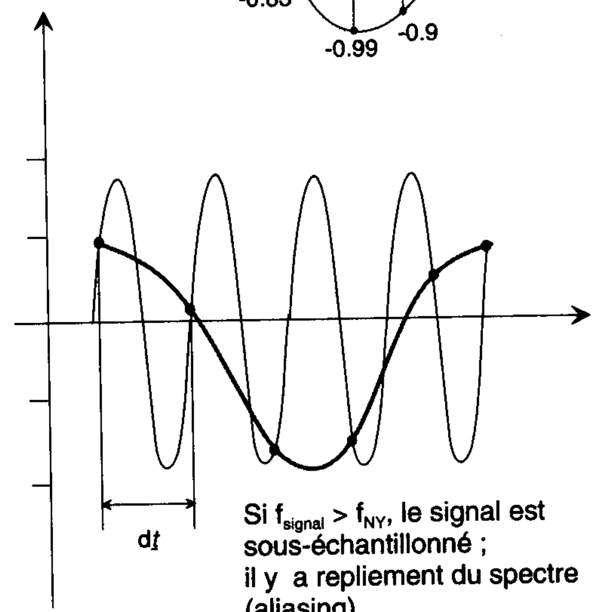


Figure 5-4. A discretized version of Eq. (4.1), showing how a sum of harmonic terms can equal an arbitrary function. The amplitudes of each harmonic term vary, being prescribed by the amplitude spectrum. The shift of the phase of each harmonic term is given by the phase spectrum. (from Lay and Wallace, 1994)





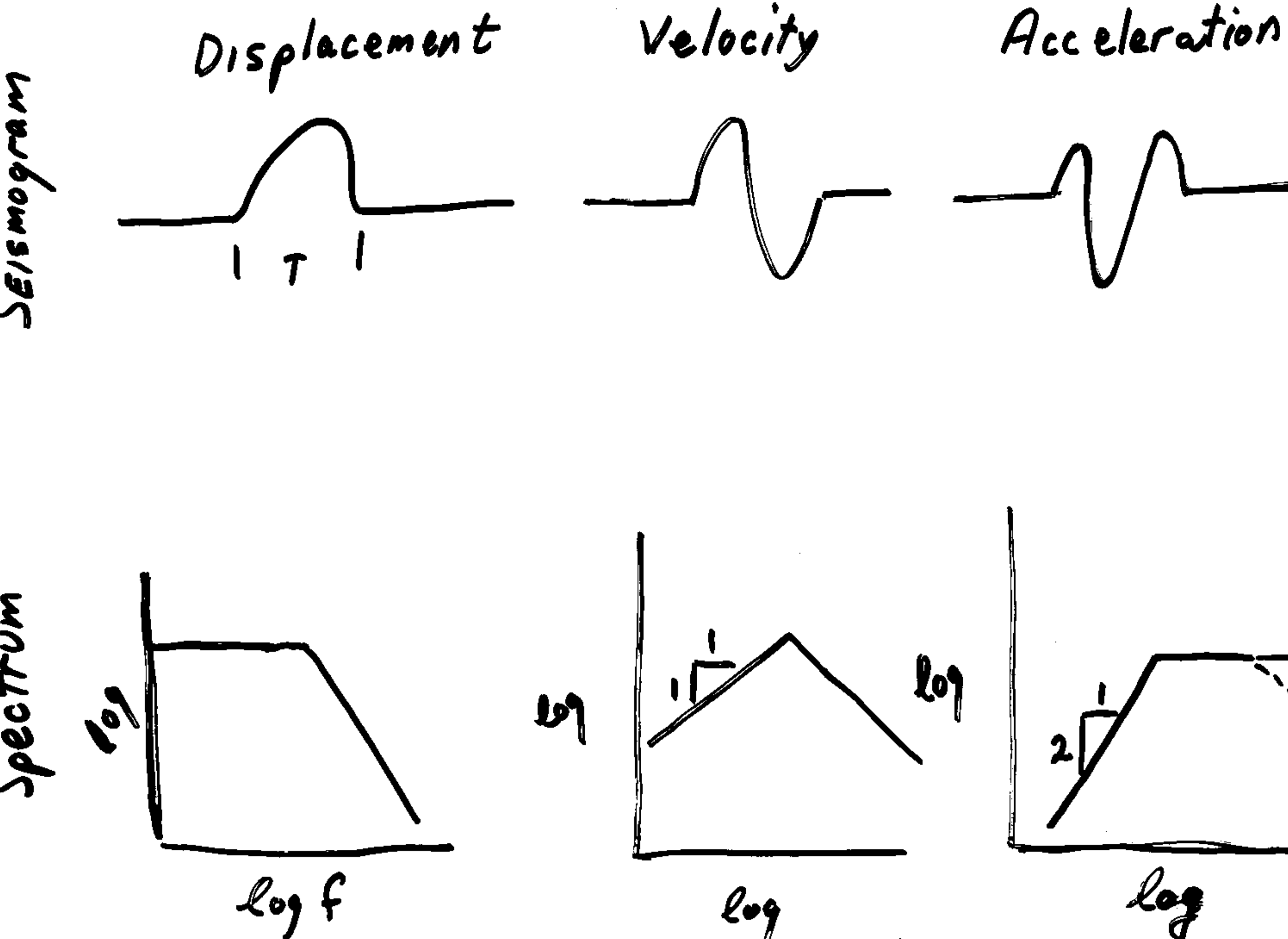
Source : Reynolds, 1997

Fourier transform

- An important property is how the Fourier transform of a derivative of a time series is related to the Fourier transform of the time series itself.

$$v(t) = \frac{d}{dt}(u(t))$$

$$|v(f)| = (2\pi f)|u(f)|$$



Displacement
Velocity
Acceleration
Seismogram
T
Spectrum
log
log f
log
1
1
log
log
log
1
2
log

http://www.ce.berkeley.edu/~mahin/CE227web/Bozorgni-CampbellCh_BerteroBozorgnia.pdf

5.3.3 Elastic Response Spectra

5.3.3.1 Definitions and Examples

The concept of elastic response spectrum was introduced by Maurice A. Biot (Biot 1933, 1934, 1941; see also Bozorgnia, 2003; and Chapter 1). The technique is now a fundamental method in earthquake engineering (Housner 1941; Housner et al., 1953; Hudson, 1962). The elastic response spectrum represents the maximum response (over time) of a linear elastic SDF system versus its natural period (or frequency) when excited by a ground acceleration time history. The natural period, T (sec), of the SDF system is related to the circular frequency, ω (rad/sec), and cyclic frequency, f (cycles/sec or Hz), through the expression

$$\omega = \sqrt{(k/m)} = 2\pi f = 2\pi/T \tag{5.6}$$

where k and m are the stiffness and mass of the system, respectively. The SDF system can have different values of damping ratio, usually specified as a percentage of the critical damping (e.g., see Chopra, 2001). The response quantity of the SDF system can be one of the following:

S_d = maximum deformation of the SDF system relative to the ground
SV = maximum velocity of the SDF system relative to the ground
SA = maximum absolute (total) acceleration of the SDF system
S_v (or PSV) = pseudo-velocity = ωS_d
S_a (or PSA) = pseudo-acceleration = $\omega^2 S_d$

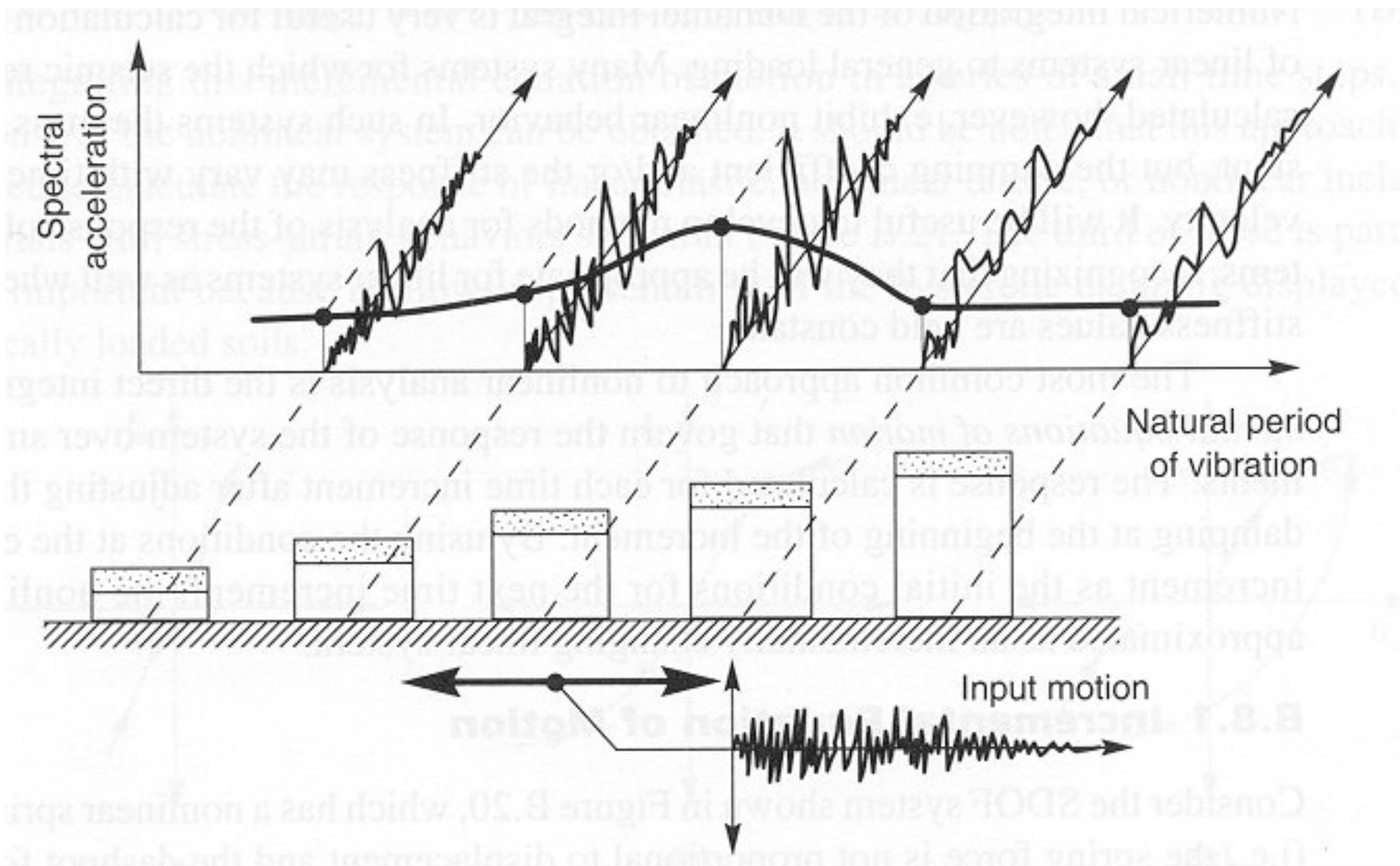
For response spectra, the absolute values of these quantities are used. The maximum elastic restoring force (or the base shear) in the SDF system is

$$F_e = k\,S_d = m\,\omega^2 S_d = m\,S_a \tag{5.7}$$

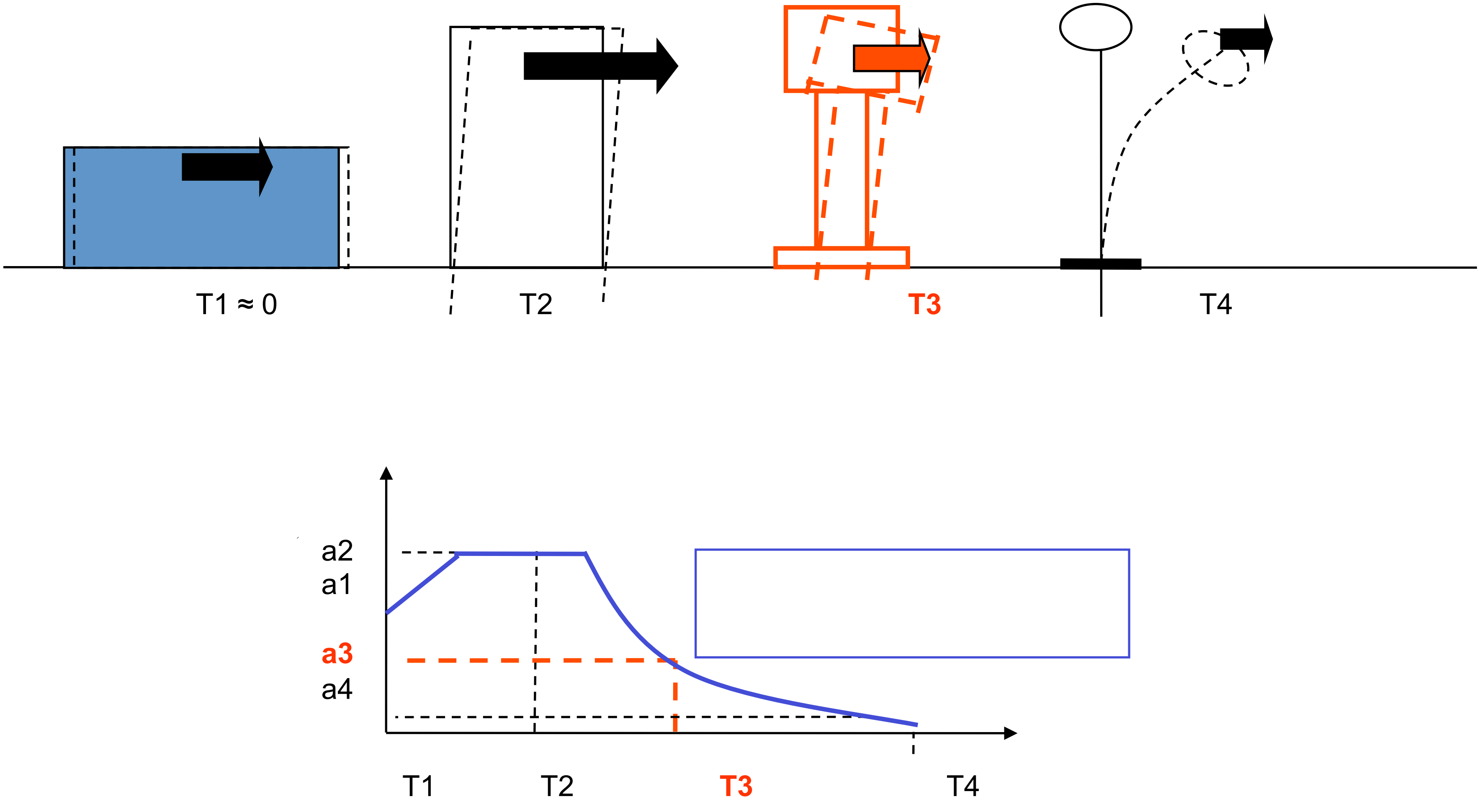
SDF: single degree of freedom

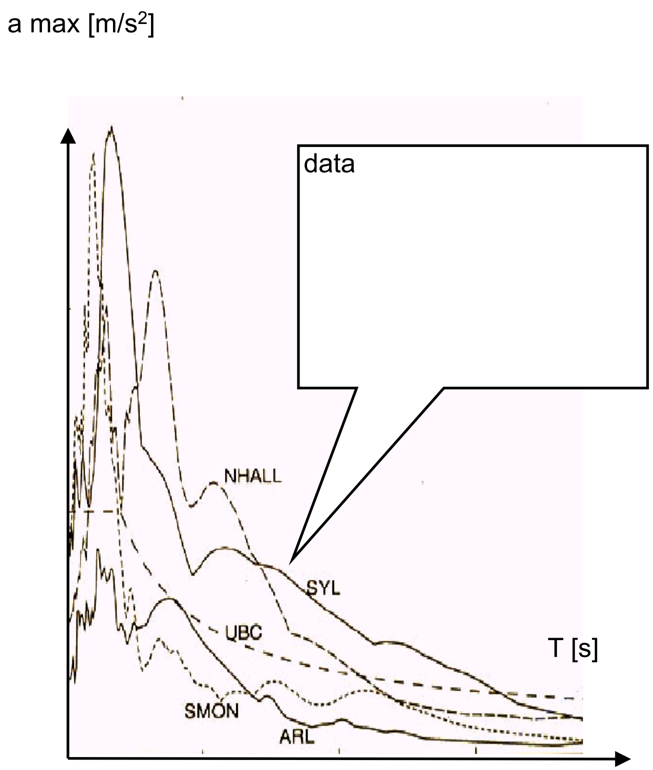
Response spectrum

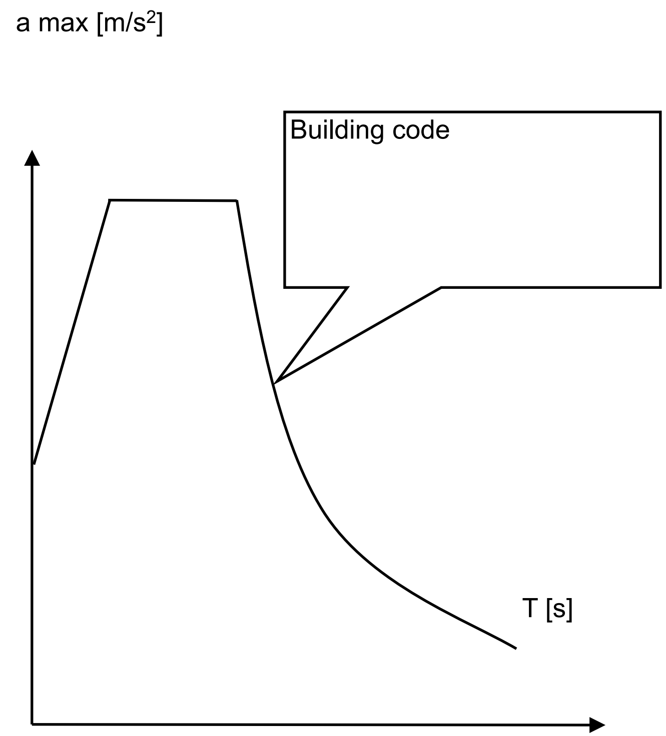
$|\ddot{u}|$



T period, ζ damping




a max [m/s²]
data
NHALL
SYL
UBC
SMON
ARL
T [s]


a max [m/s²]
Building code
T [s]

Response spectrum and pseudo-response spectrum

PSA, PSV and PSD are not used if T>>1s or ς >20%

$$S_d = |u|_{\max}$$

$$S_v = |\dot{u}|_{\max} \simeq \omega_0 S_d = PSV$$

$$S_A = |\ddot{u}|_{\max} \simeq \omega_0^2 S_d = \omega_0 PSV = PSA$$

Links between Sa and ground-motion

Sa(T=0, ζ) = PGA whateverζ

Sd(T=∞, ζ) = PGD whatever ζ

Response and Fourier spectra are different !!!!

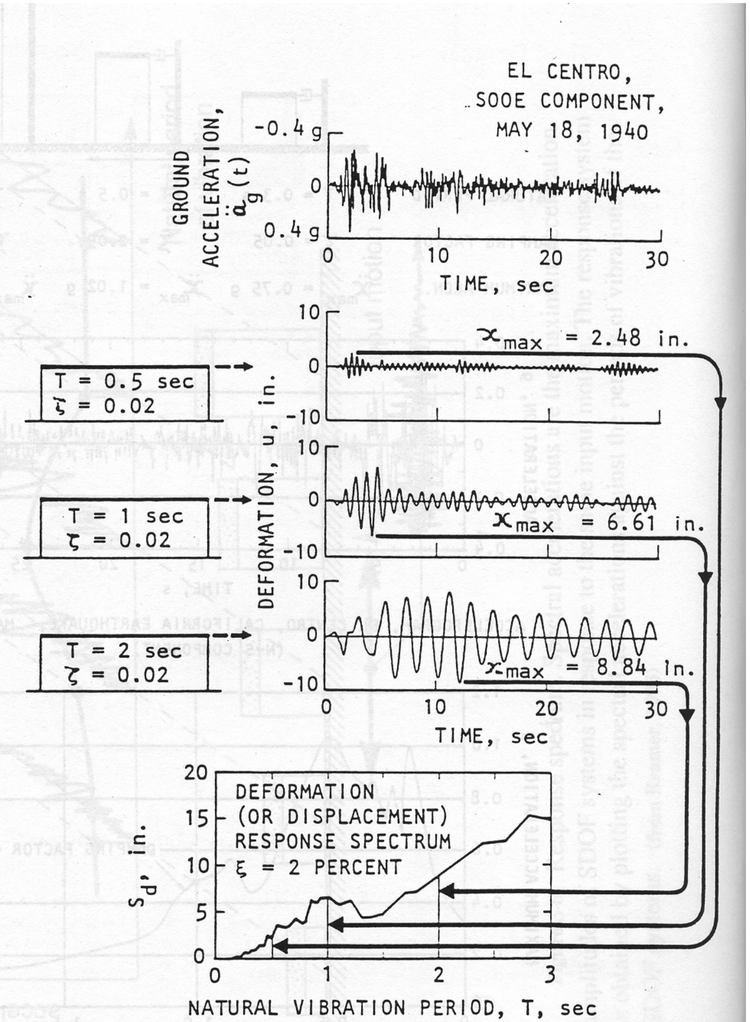
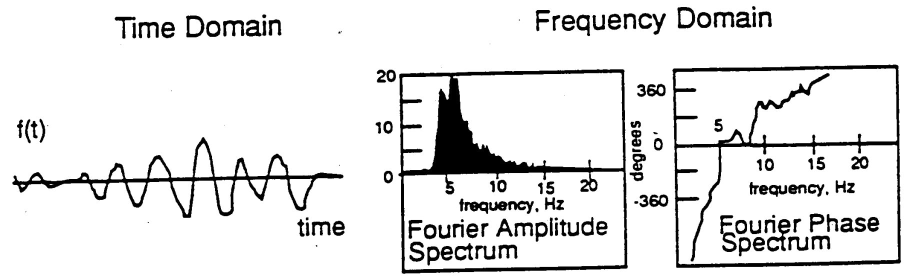


Figure 5-7. Computation of deformation (or displacement) response spectrum (from Chopra, 1981)



A signal that is a function of time, as shown on the left, may be equivalently represented by its Fourier spectrum, as shown on the right. The amplitude and phase spectra are both needed to provide the complete time series.

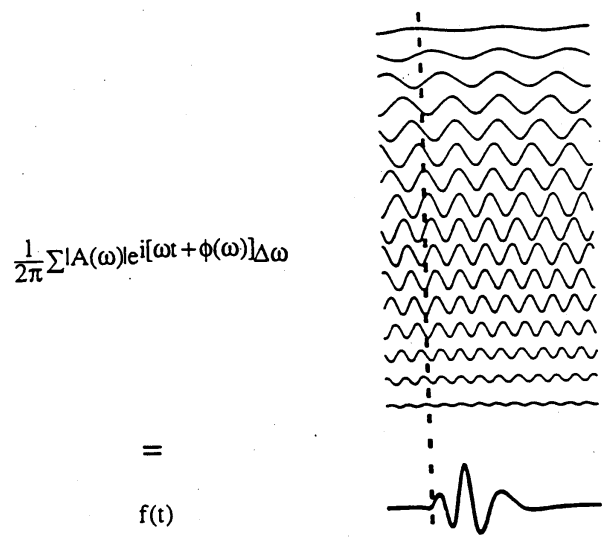


Figure 5-4. A discretized version of Eq. (4.1), showing how a sum of harmonic terms can equal an arbitrary function. The amplitudes of each harmonic term vary, being prescribed by the amplitude spectrum. The shift of the phase of each harmonic term is given by the phase spectrum. (from Lay and Wallace, 1994)

El Centro

NRC RG I.60 response spectrum

AMORTISSEMENTS REDUITS 2 % - 5 % - 7 % - 10 % - 20 % - 50 %

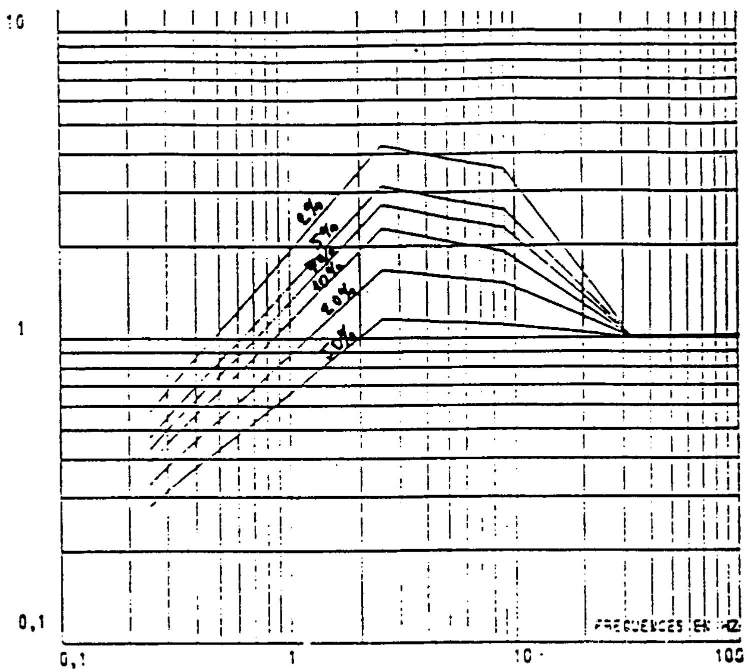
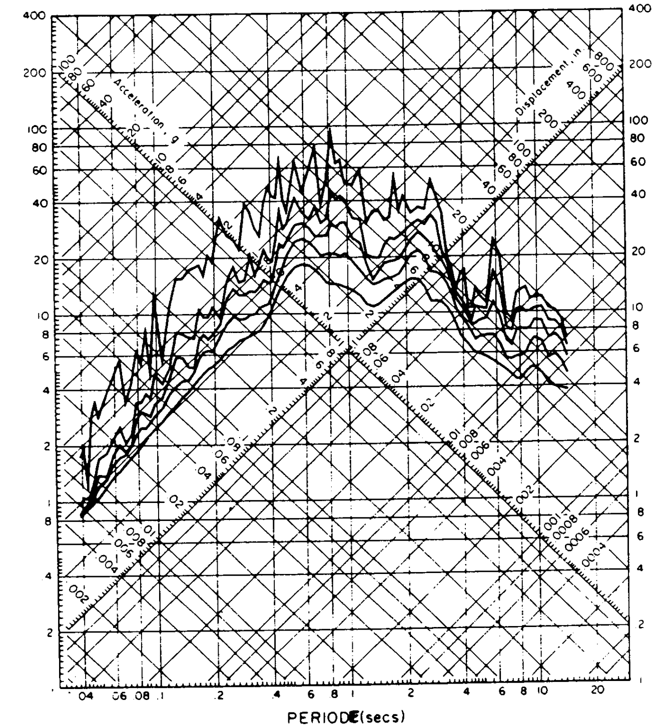
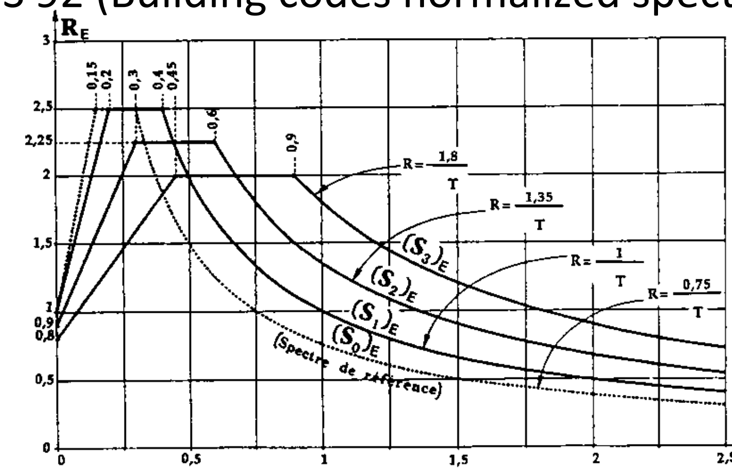


TABLE DES EXTREMITES DES SEGMENTS

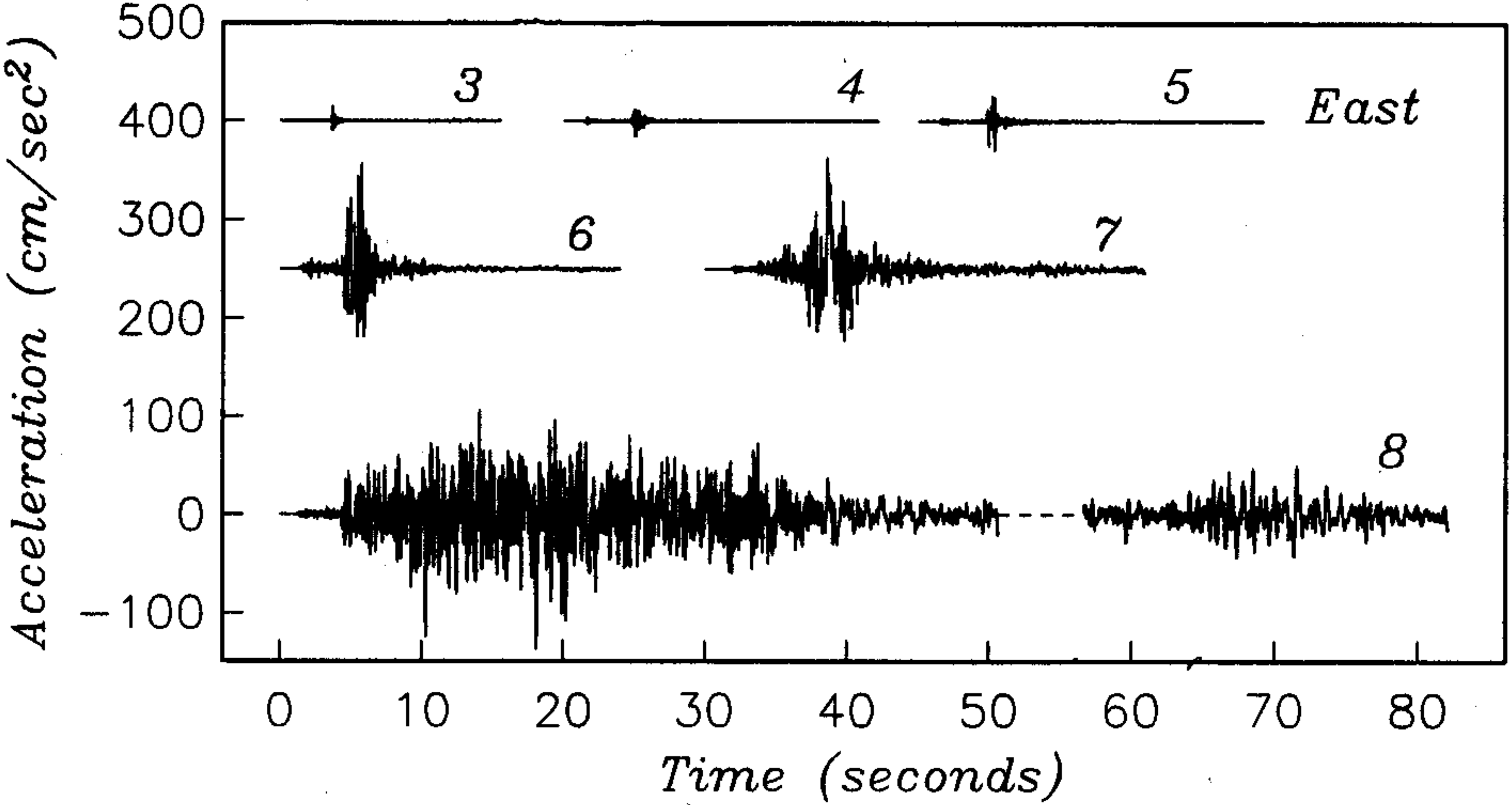
FREQUENCE (Hz)		0,25	2,50	9	33	100
AMORTISSEMENT REDUIT (%)	2	0,57	4,25	3,54	1	1
	5	0,47	3,13	2,61	1	1
	7	0,43	2,72	2,27	1	1
	10	0,39	2,28	1,90	1	1
	20	0,33	1,67	1,50	1	1
	50	0,28	1,15	1,10	1	1



PS 92 (Building codes normalized spectra)



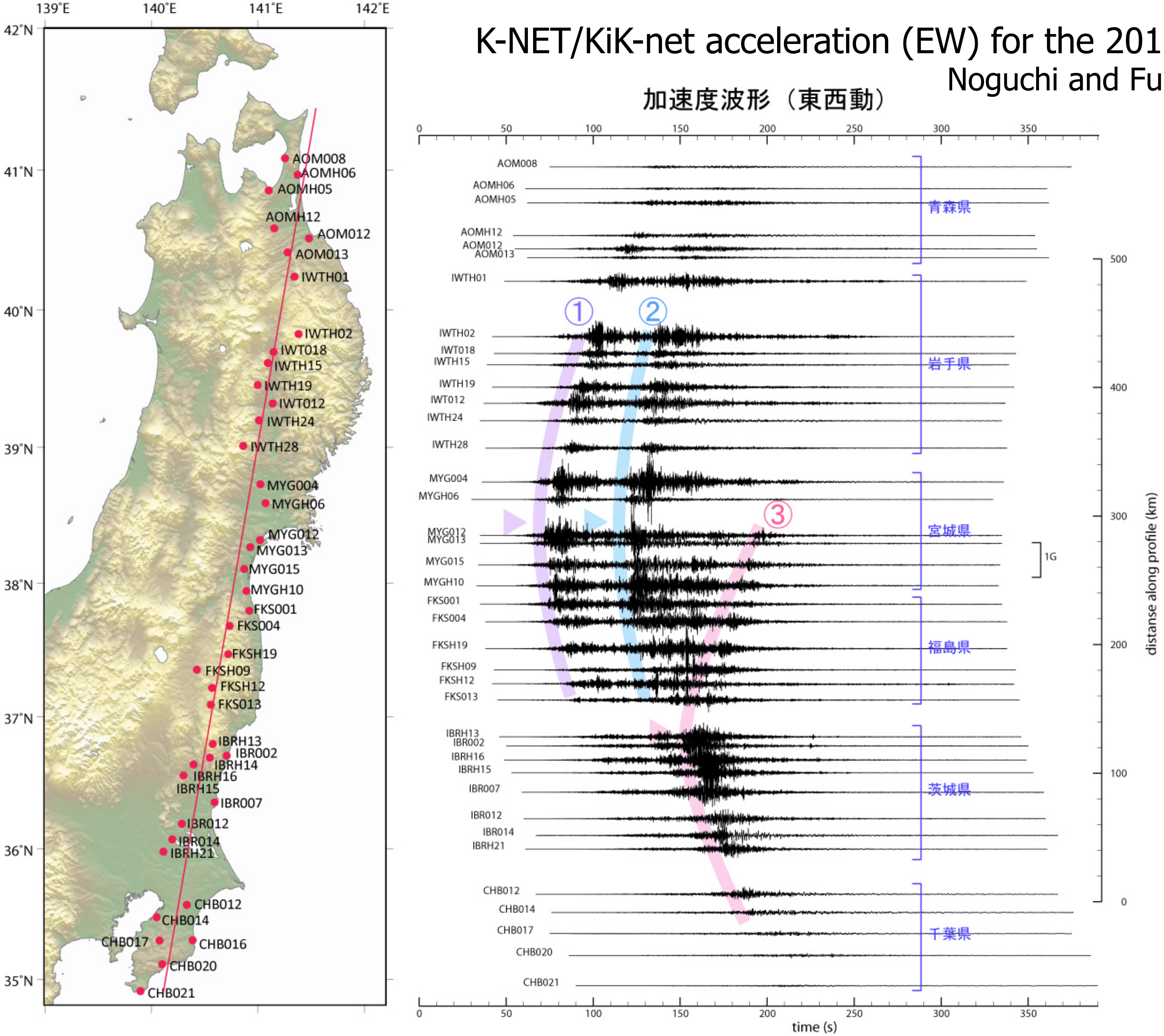
How size of earthquake matters

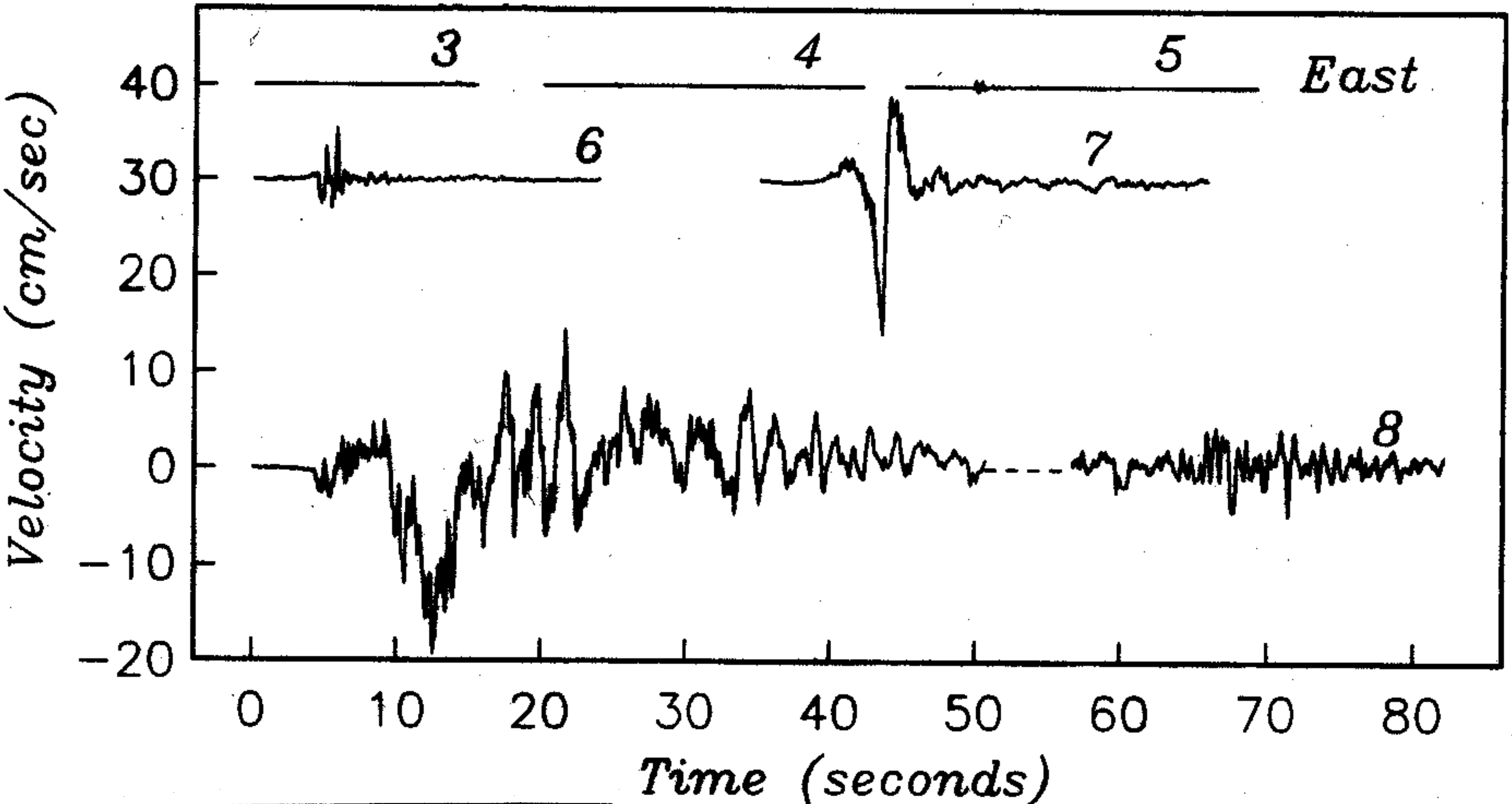


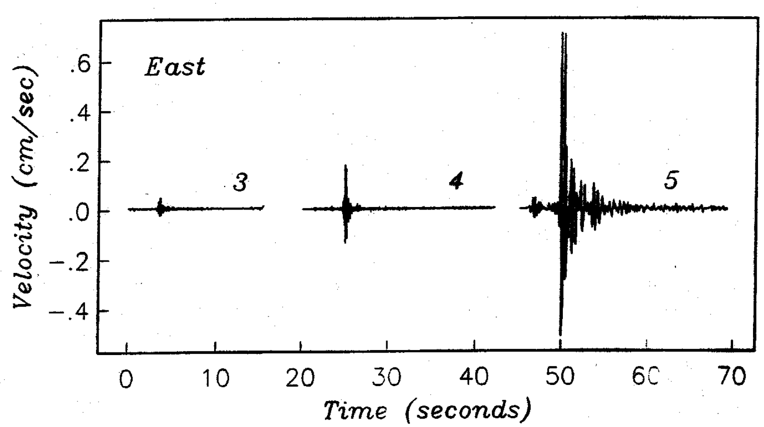
500
400
300
200
100
0
−100
Acceleration (cm/sec2)
3
4
5
East
6
7
8
0
10
20
30
40
50
60
70
80
Time (seconds)

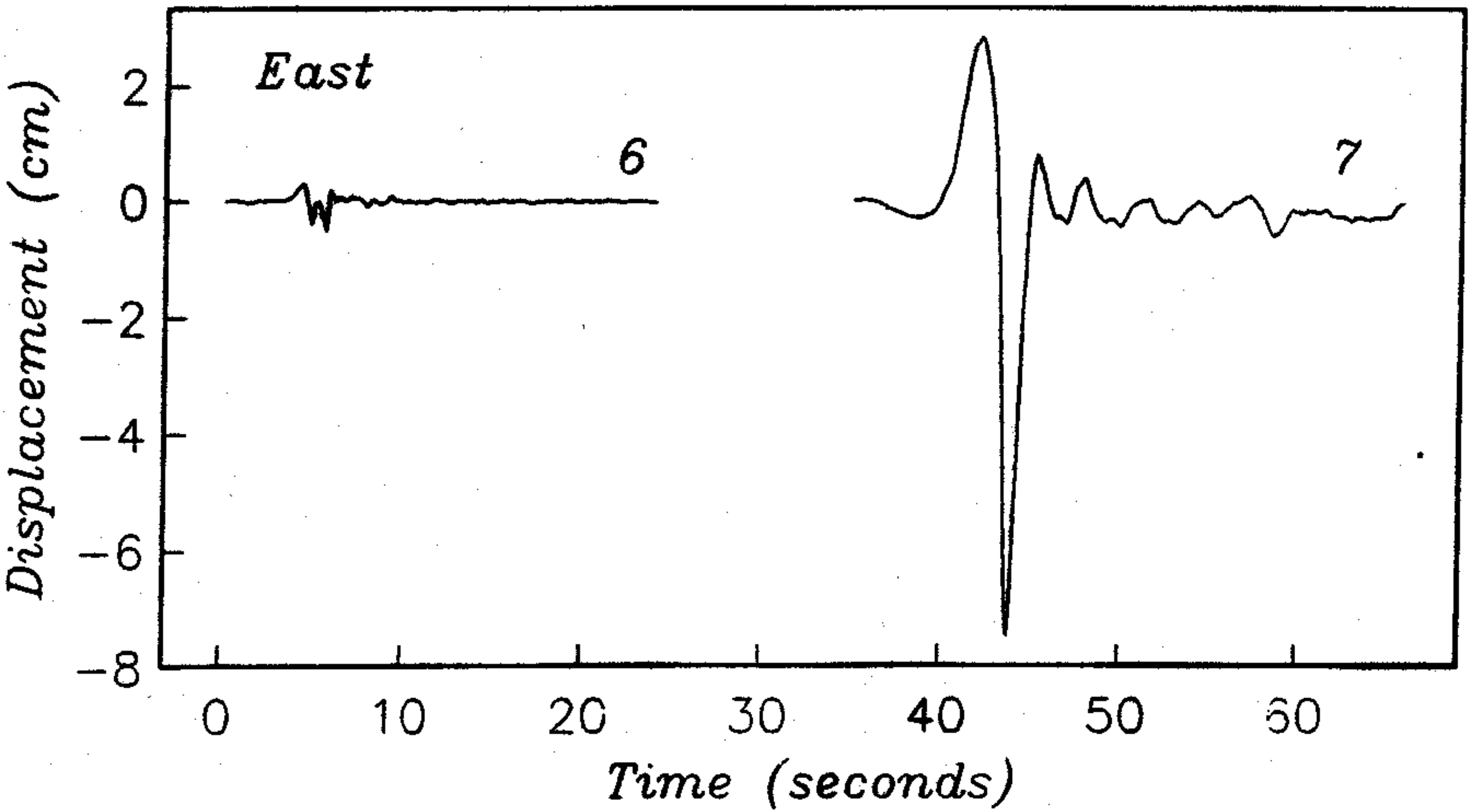
K-NET/KiK-net acceleration (EW) for the 2011 Tohoku eq.

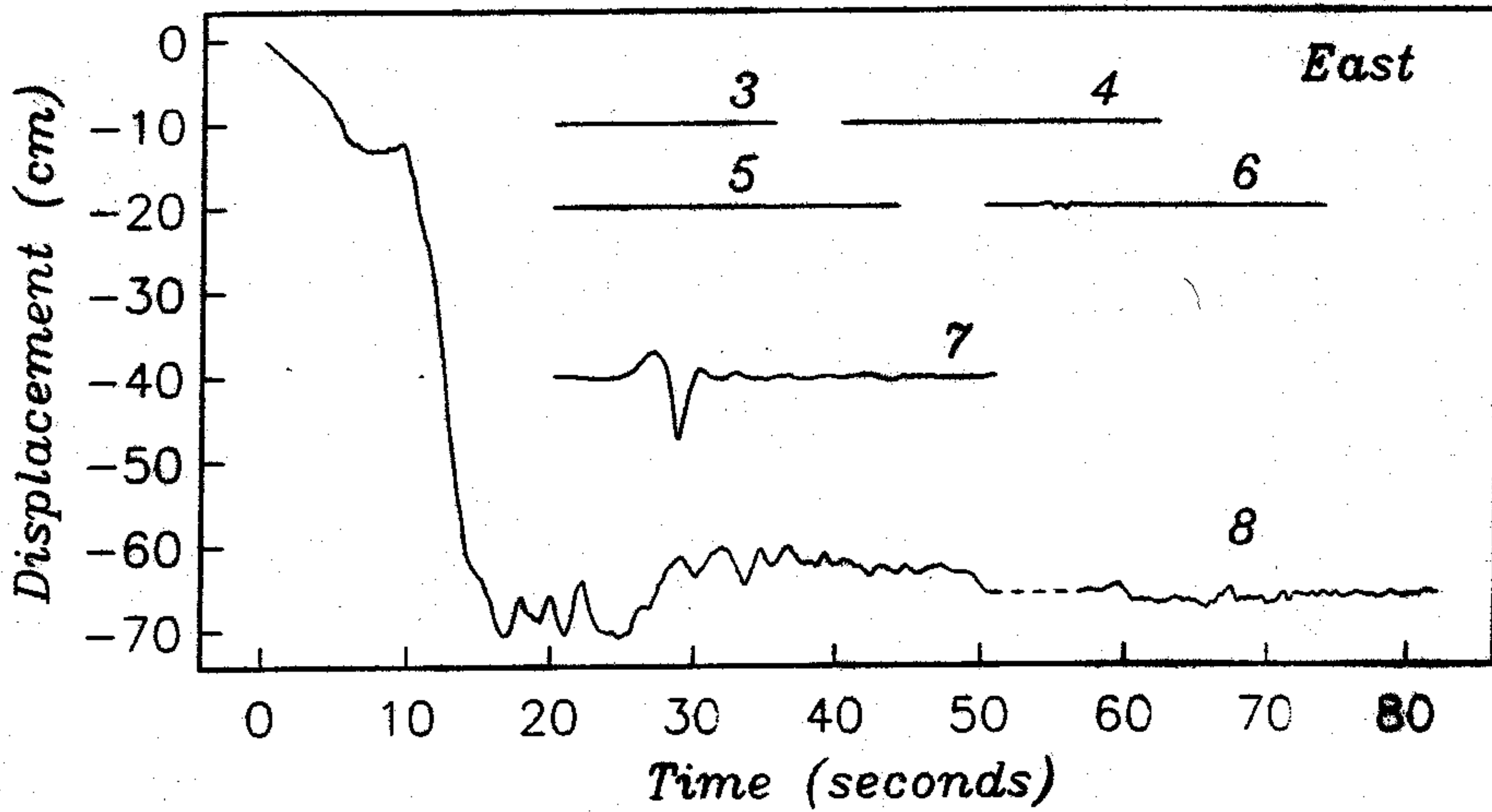
Noguchi and Furumura (2011)




East
3
4
5
6
7
8
Velocity (cm/sec)
40
30
20
10
0
−10
−20
0
10
20
30
40
50
60
70
80
Time (seconds)


East
3
4
5
Velocity (cm/sec)
.6
.4
.2
.0
−.2
−.4
0
10
20
30
40
50
60
70
Time (seconds)

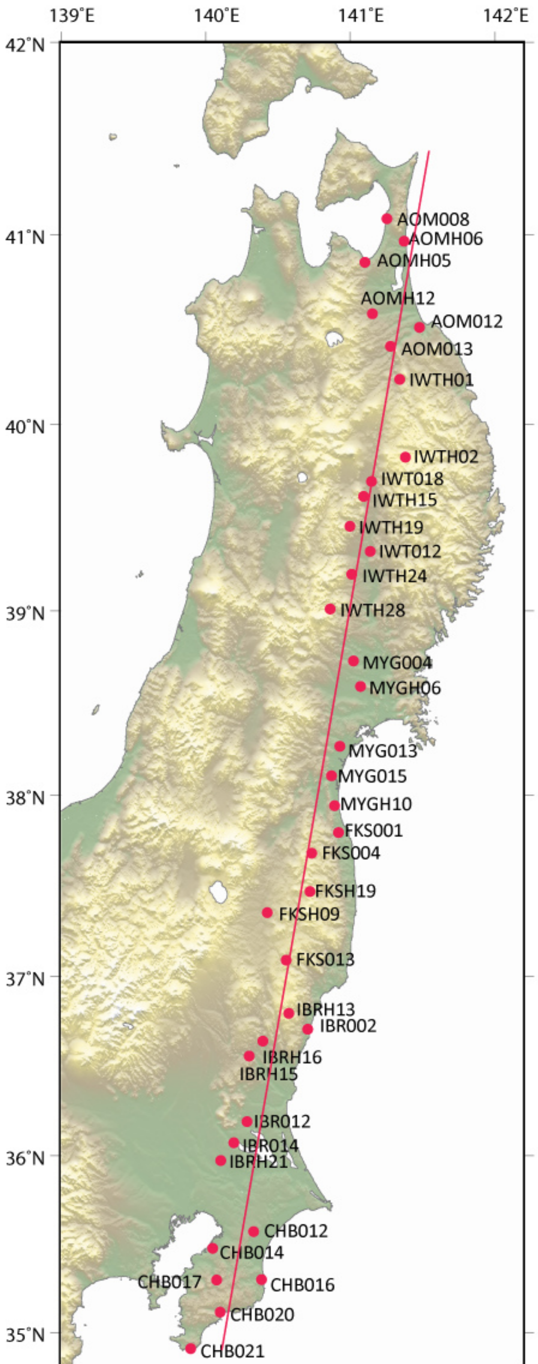

East
6
7
2
0
−2
−4
−6
−8
Displacement (cm)
0
10
20
30
40
50
60
Time (seconds)

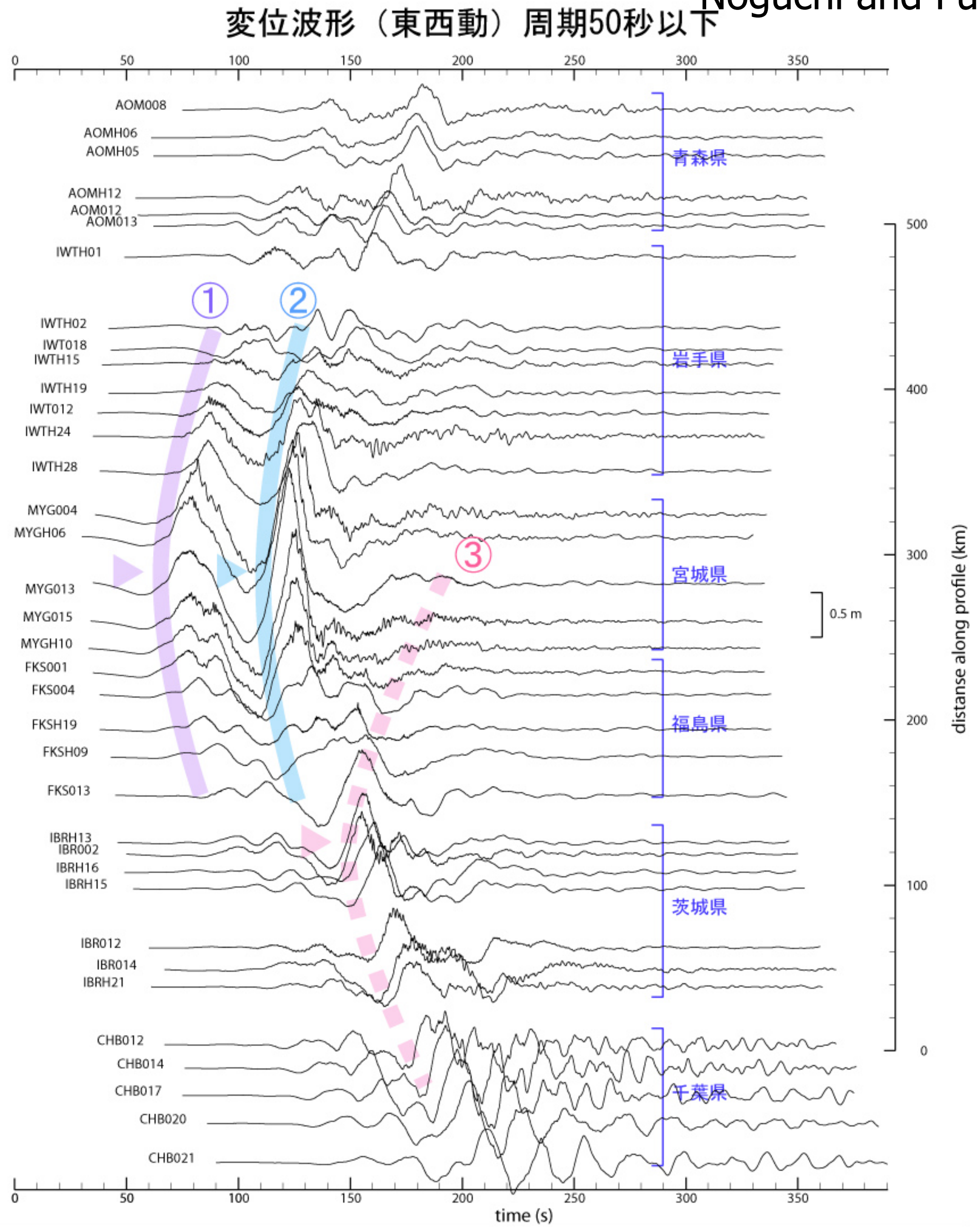


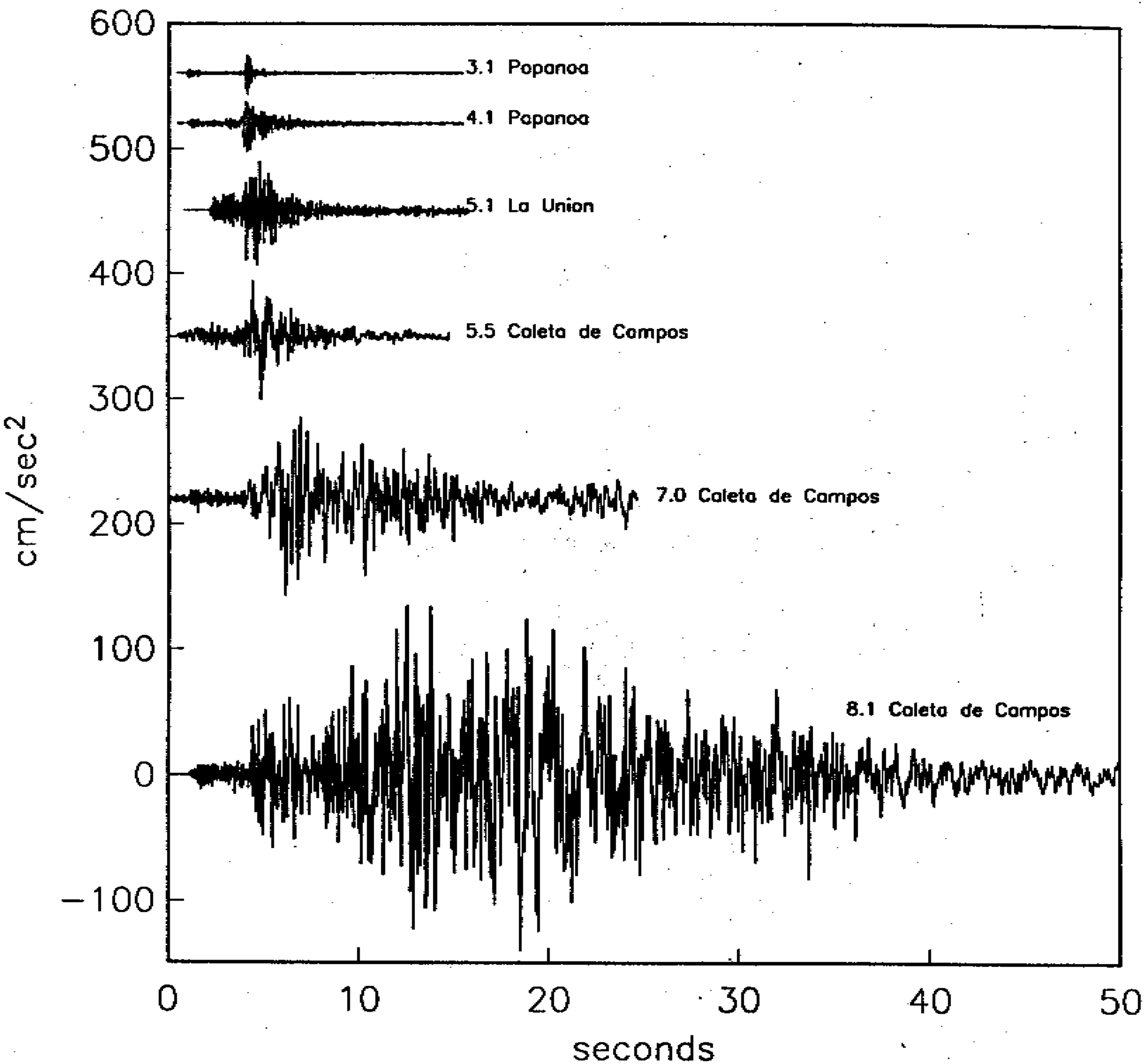
East
3
4
5
6
7
8
Displacement (cm)
0
−10
−20
−30
−40
−50
−60
−70
0
10
20
30
40
50
60
70
80
Time (seconds)

K-NET/KiK-net displacement (EW) for the 2011 Tohoku eq.

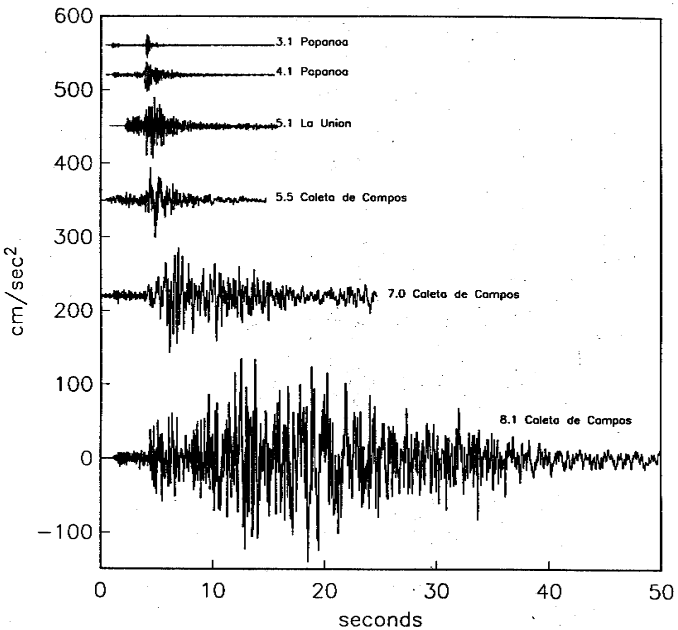
Noguchi and Furumura (2011)

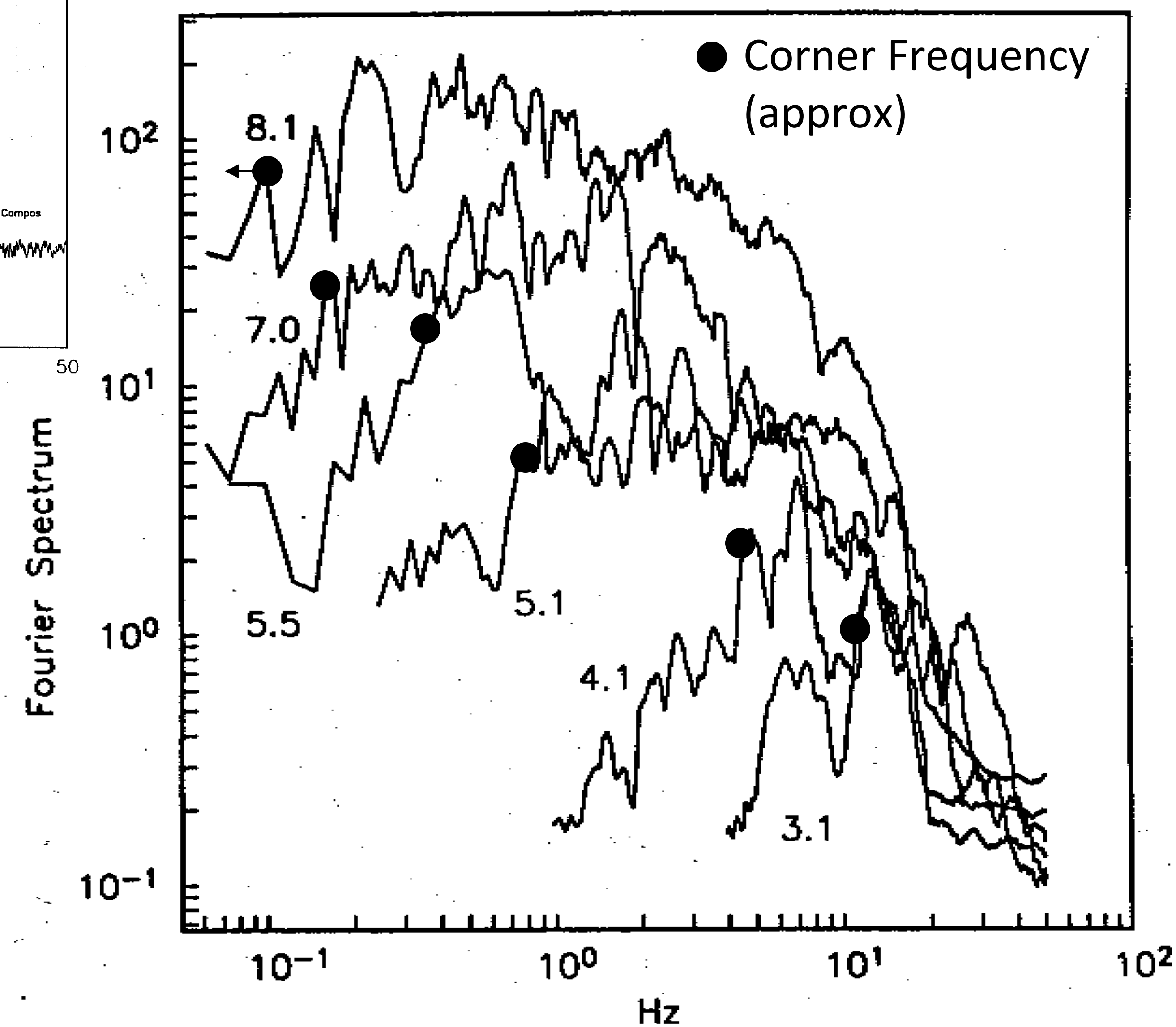


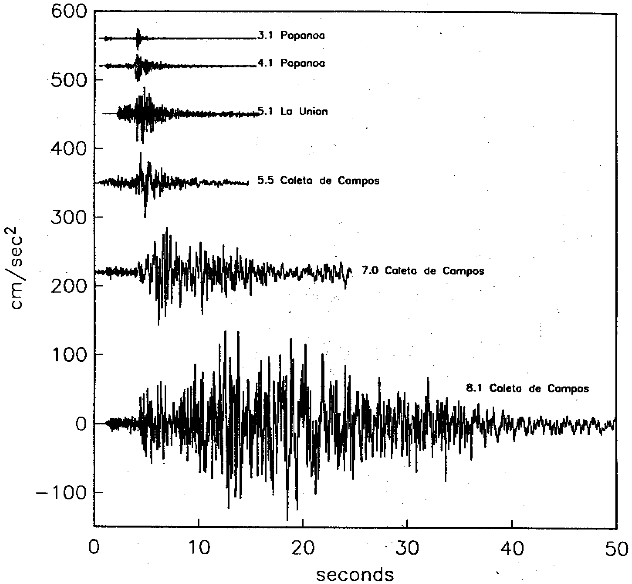


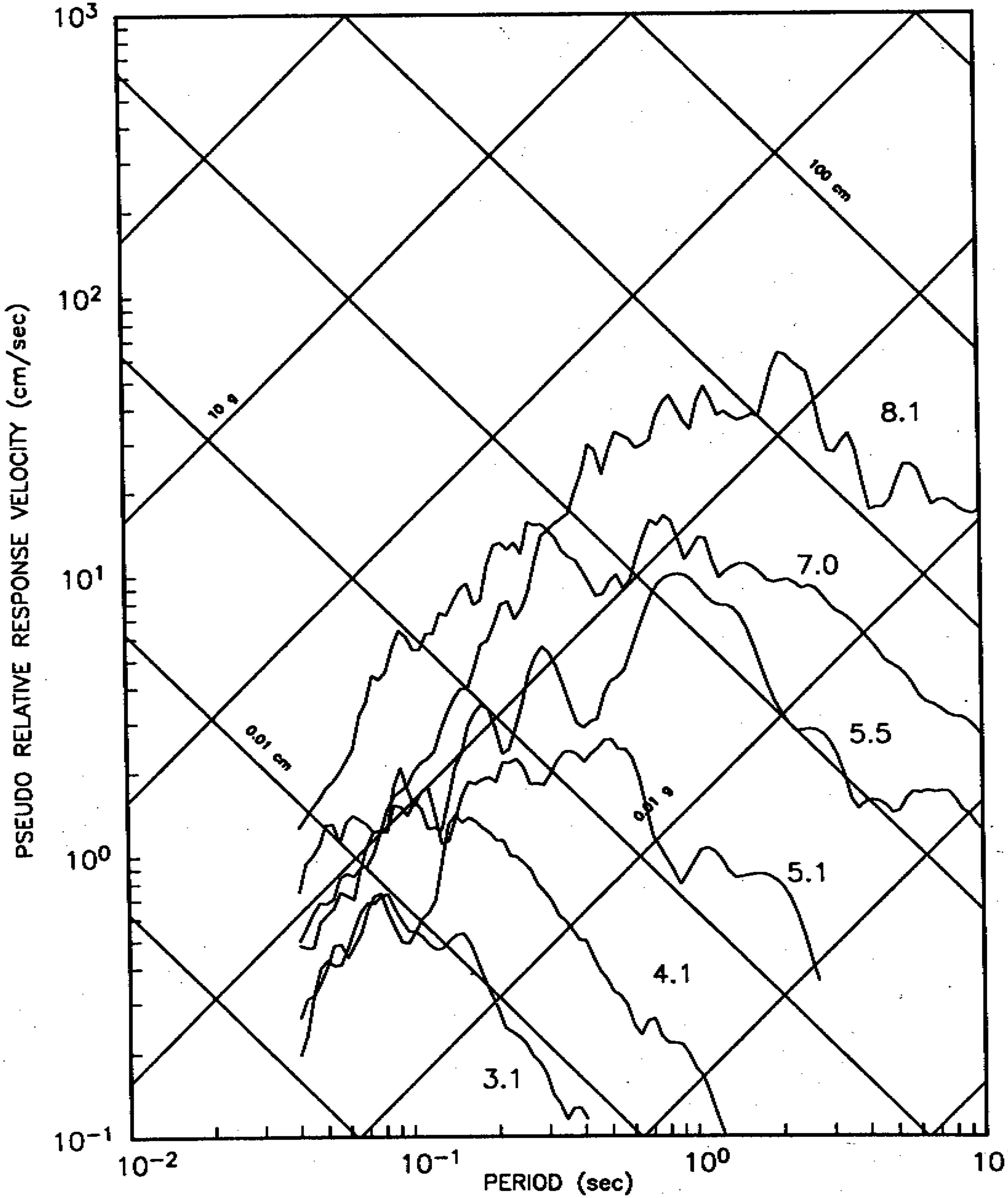

600
500
400
300
200
100
0
−100
cm/sec^2
3.1 Papanoa
4.1 Papanoa
5.1 La Union
5.5 Caleta de Campos
7.0 Caleta de Campos
8.1 Caleta de Campos
0
10
20
30
40
50
seconds

Scaling of strong motion in Guerrero, Mexico






3.1 Papanoa
4.1 Papanoa
5.1 La Union
5.5 Caleta de Campos
7.0 Caleta de Campos
8.1 Caleta de Campos
cm/sec²
seconds
600
500
400
300
200
100
0
−100
0
10
20
30
40
50


PSEUDO RELATIVE RESPONSE VELOCITY (cm/sec)
PERIOD (sec)
100 cm
10 g
0.01 cm
0.01 g
8.1
7.0
5.5
5.1
4.1
3.1

Exceptional Accelerations (Before Tohoku earthquake)

1. Nahanni 1985 Site 1, 2380 cm/s^2
2. Northridge Tarzana, 1970 cm/s^2
3. Cape Mendocino, 1843 cm/s^2
4. 2004 Niigata Kawaguchi, 1839 cm/s^2
5. Imperial Valley 1979 El Centro Array #6, 1778 cm/s^2
6. 2004 Niigata Tohkamachi, 1765 cm/s^2
7. Northridge Pacoima Dam, 1743 cm/s^2
8. 2003 Miyagi Oki MYG011 Oshika, 1587 cm/s^2
9. 2004 Niigata NIG019 Ojiya, 1533 cm/s^2
10. Gazli Karakyr, 1430 cm/s^2

Total of 35 records with PGA>980 cm/s^2

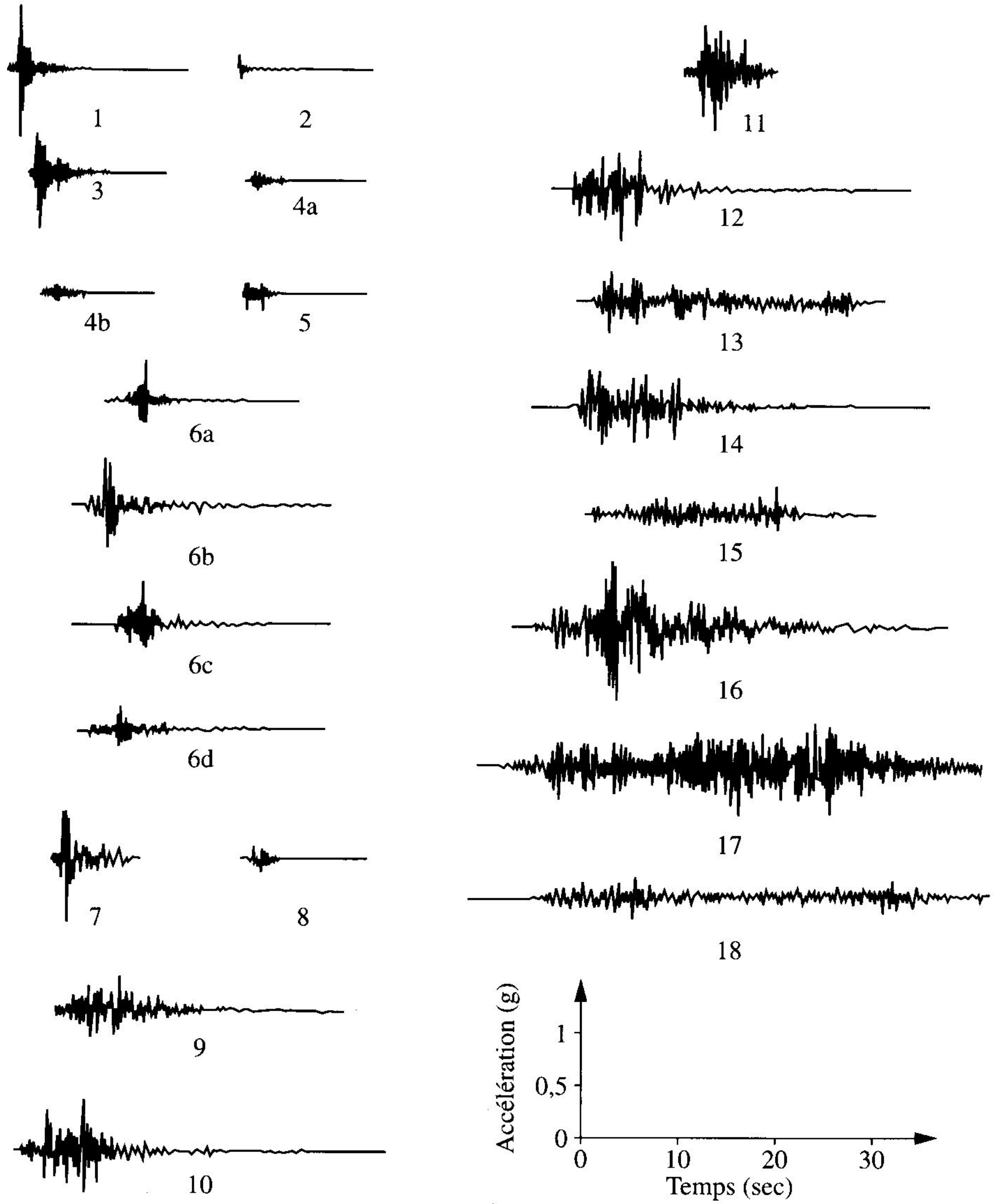
Courtesy of J. Anderson

Exceptional Velocities (Before Tohoku earthquake)

1. Chi Chi TCU068, 318 cm/s
2. Chi-Chi TCU052, 200 cm/s
3. Kobe Takatori, 170 cm/s
4. Northridge Rinaldi Receiving Station, 160 cm/s
5. Kashiwazaki Niigata-2007- NIG018, 152 cm/s
6. Chi-Chi TCU065, 151 cm/s
7. Landers Lucerne, 147 cm/s
8. Niigata 2004- Kawaguchi, 144 cm/s
9. Cape Mendocino, 138 cm/s
10. Niigata NIG019, 137 cm/s

Total of 41 records with PGV>100 cm/s

Courtesy of J. Anderson



N°	Séisme et station d'enregistrement	M	A [g]
1	Stone Canyon 1972 Melendy Ranch	4,6	0,71
2	Port Huëneme 1957	4,7	0,17
3	Ancona 1972 Rocca	4,9	0,61
4a	San Francisco 1957 , Golden Gate Park	5,3	0,12
4b	San Francisco 1957, State Building	5,3	0,10
5	Lytle Creek 1970	5,4	0,20
6a	Parkfield 1966, Temblor	5,6	0,41
6b	Parkfield 1966, Station N°2	5,6	0,51
6c	Parkfield 1966, Station N°5	5,6	0,47
6d	Parkfield 1986, Station N°8	5,6	0,28
7	San Salvador 1986, GIC	5,6	0,69
8	Helena 1935	6,0	0,16
9	Managua 1972	6,2	0,38
10	Coalinga 1983, Pleasant Valley	6,2	0,60
11	Koyna 1967, Koyna dam	6,5	0,63
12	Imperial Valley 1979, Bonds Corner	6,5	0,78
13	Imperial Valley 1940, El Centro	6,7	0,36
14	Montenegro 1979, Petrovac	7,0	0,45
15	Olympia 1949	7,1	0,31
16	Tabas 1978	7,4	0,87
17	Chili 1985, Llolleo	8,0	0,62
18	Mexique 1985, Zacatula	8,1	0,25

Betbeder-Matibet, 2003