# Integrated Surface and Borehole Strong-Motion, Soil-Response Arrays in San Francisco, California

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INTERNATIONAL WORKSHOP FOR SITE SELECTION, INSTALLATION AND OPERATION OF GEOTECHNICAL STRONG-MOTION ARRAYS:
WORKSHOP 1, INVENTORY OF CURRENT AND PLANNED ARRAYS.

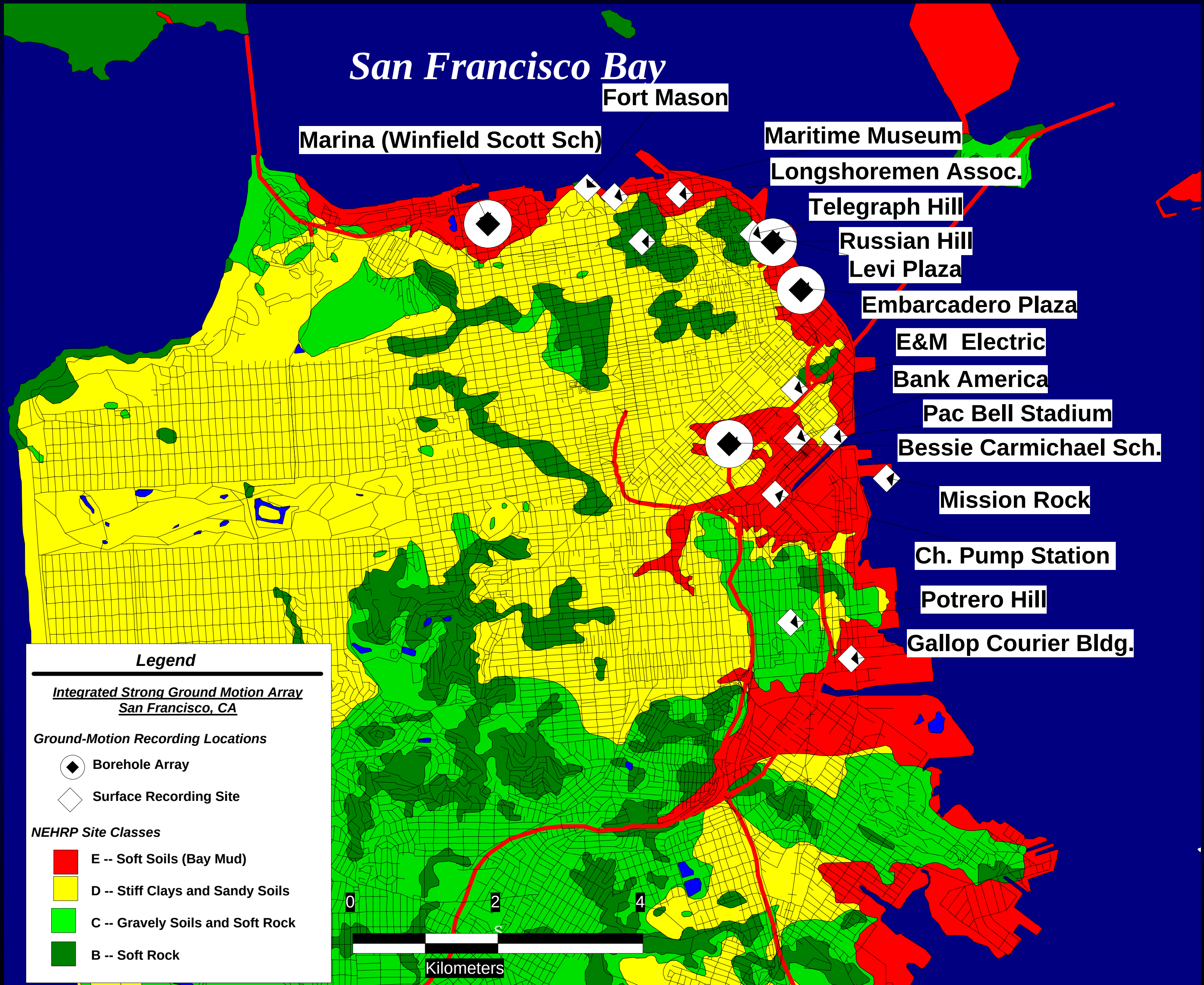
OCTOBER 14, 15, 2004

CONVENED BY
THE CONSORTIUM OF ORGANIZATIONS FOR STRONG-MOTION OBSERVATION SYSTEMS (COSMOS)

UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CA 90089

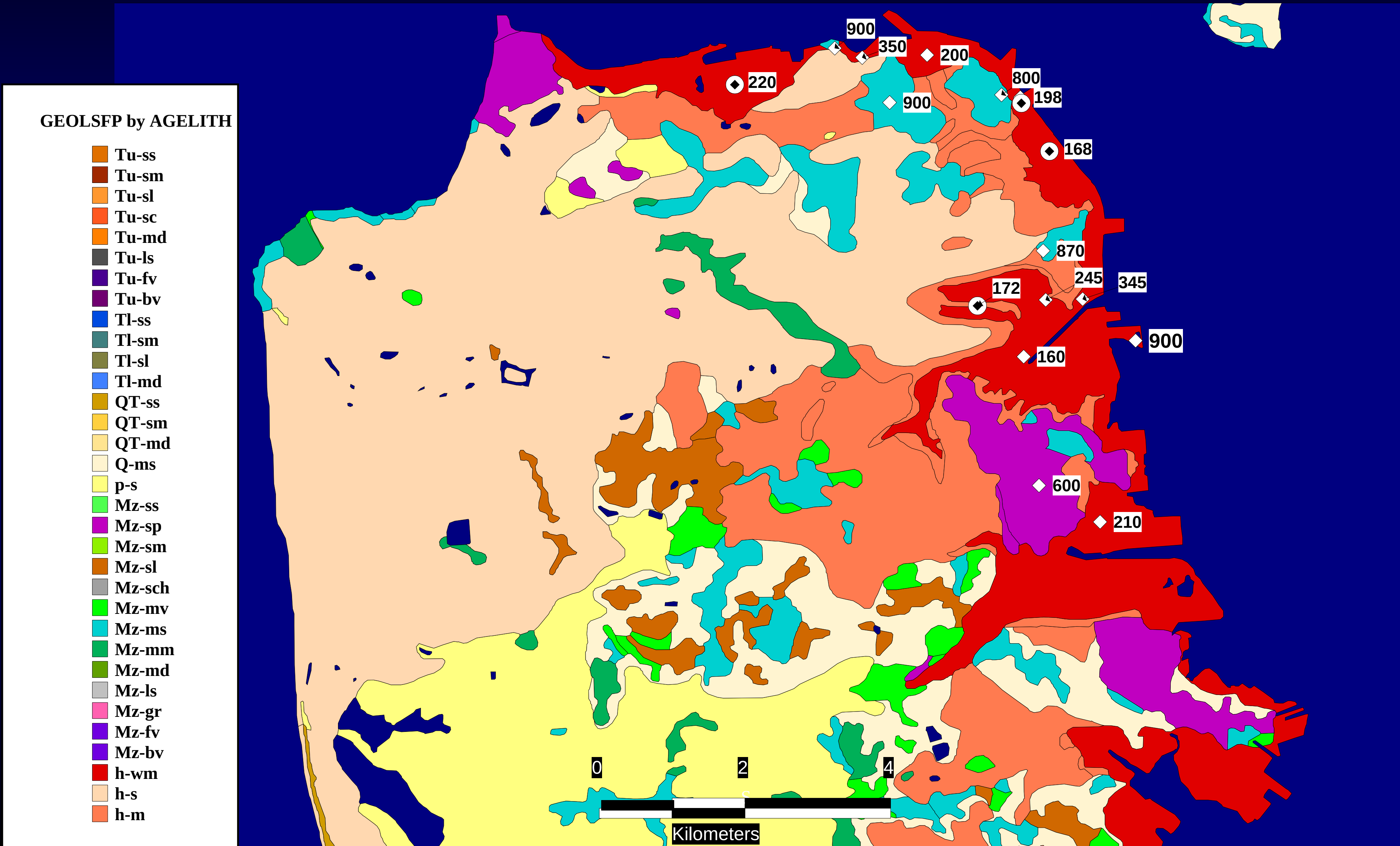
USGS
science for a changing world

# Integrated Surface and Borehole Strong-Motion Arrays in San Francisco, CA

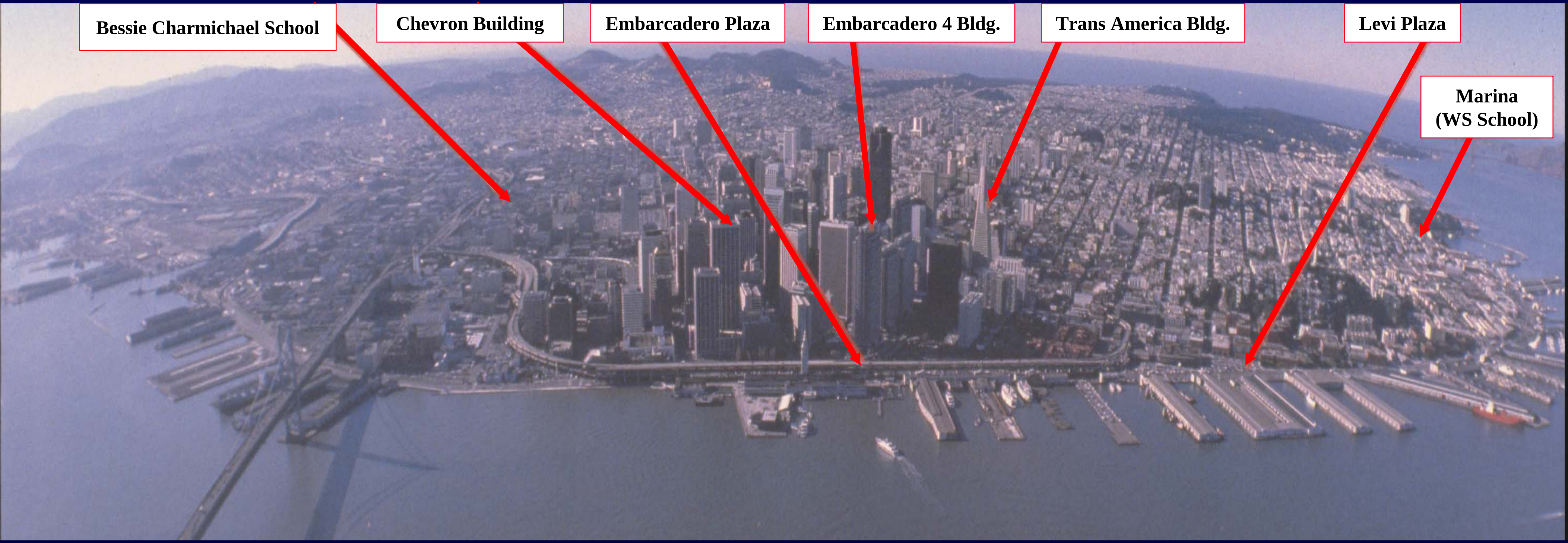


# Vs30 and Geologic Units

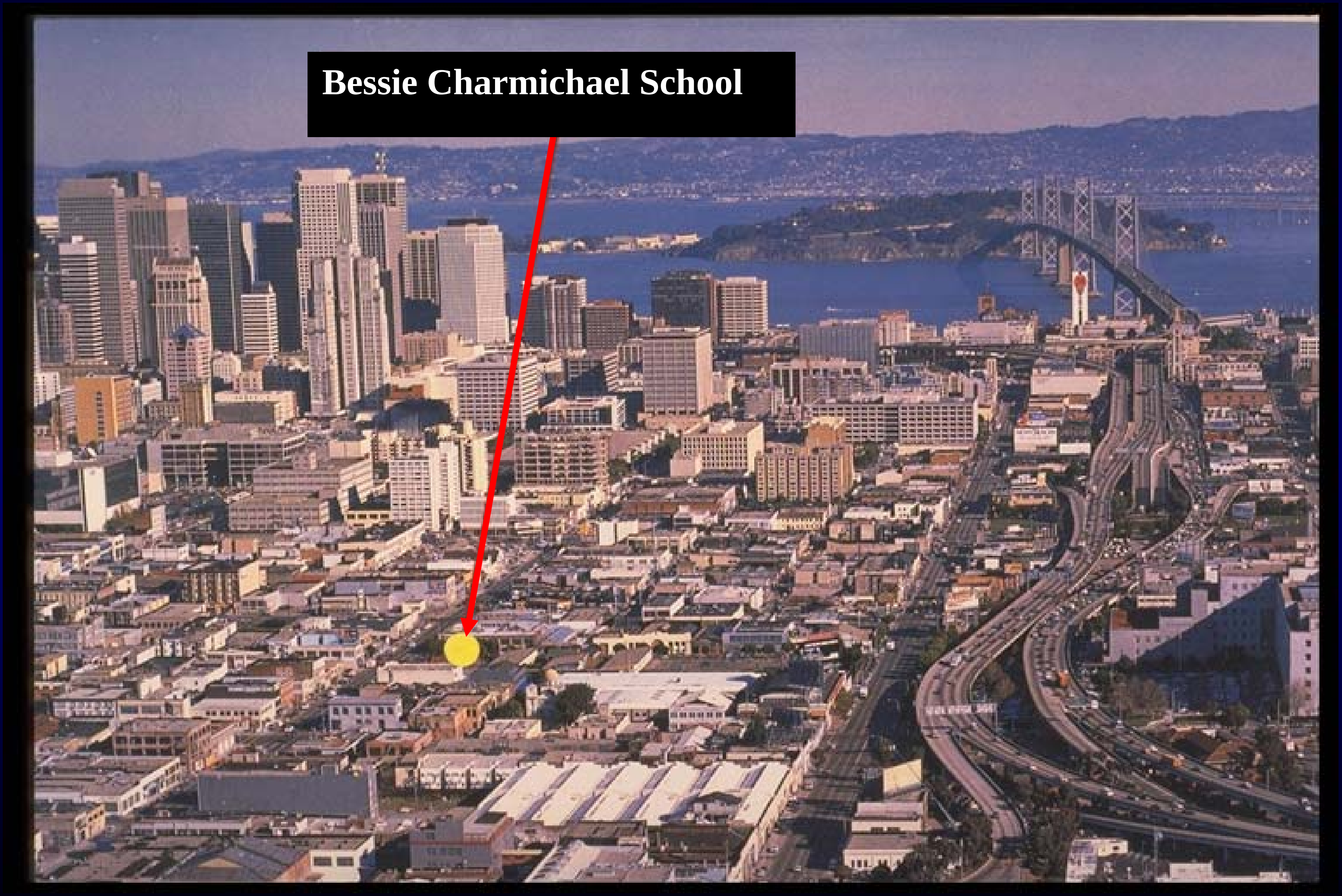
## Integrated Surface and Borehole Strong-Motion Arrays, San Francisco, CA



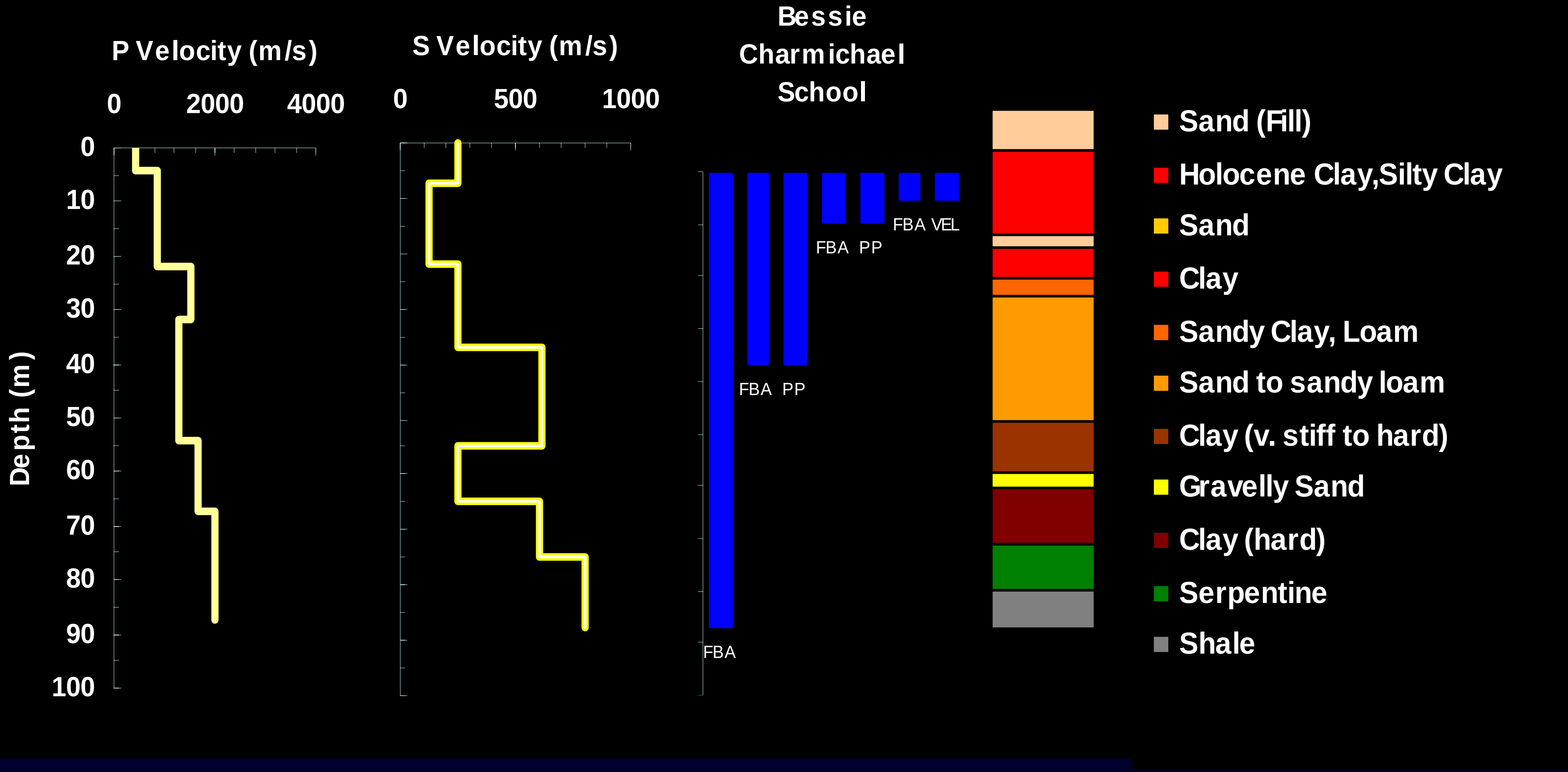
# Location of Borehole and Structural-Response Arrays
# San Francisco, CA



## Location of Borehole Array at Bessie Charmichael School
## San Francisco, CA



# Seismic and Geologic Logs for Array at Bessie Charmichael School



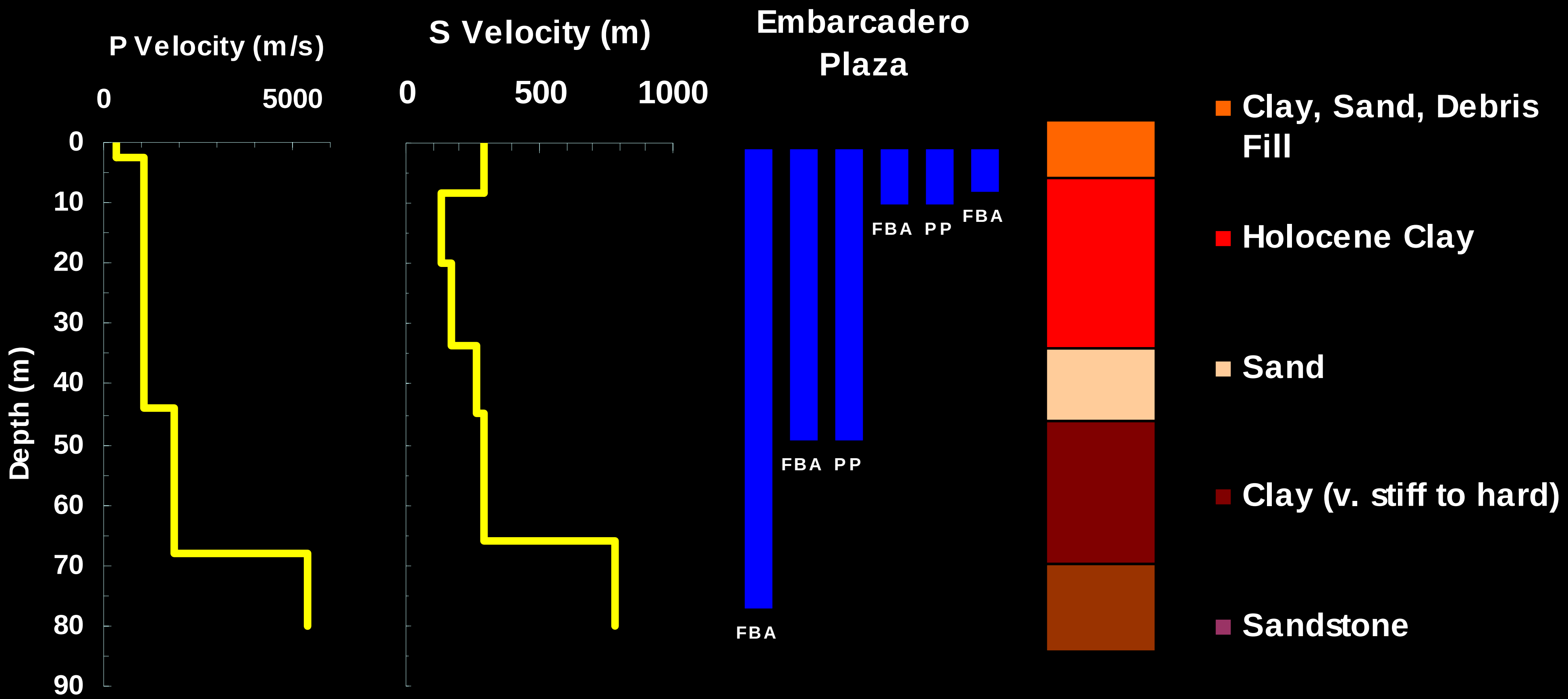
# Location of Borehole Array and Nearby Well-Instrumented Buildings near Embarcadero Plaza San Francisco, CA

Trans America (USGS)

Embarcadero Four (CDMG)

Embarcadero Plaza Array (USGS)

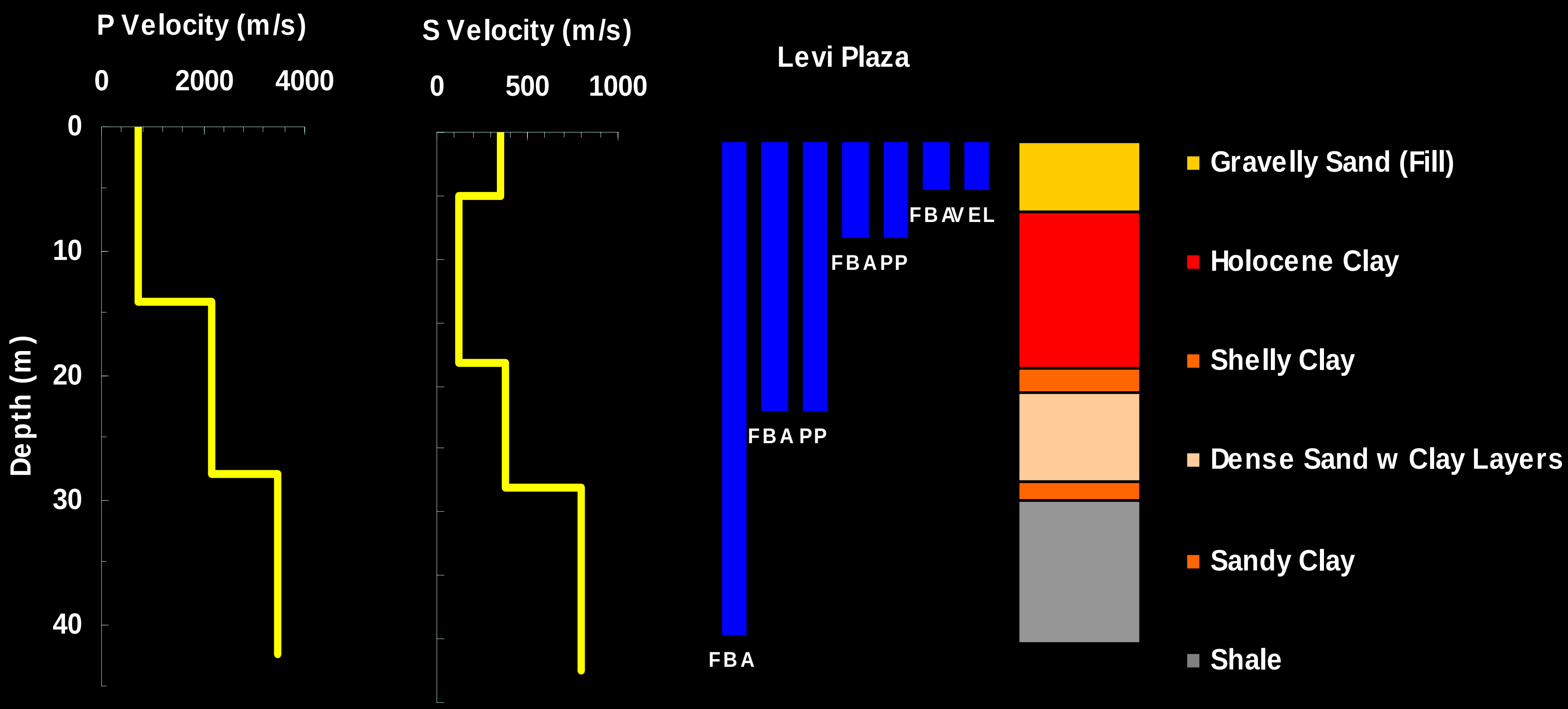
# Seismic and Geologic Logs for Array at Embarcadero Plaza



# Location of Borehole Array and Surface Recorder on Rock near Levi Plaza San Francisco, CA

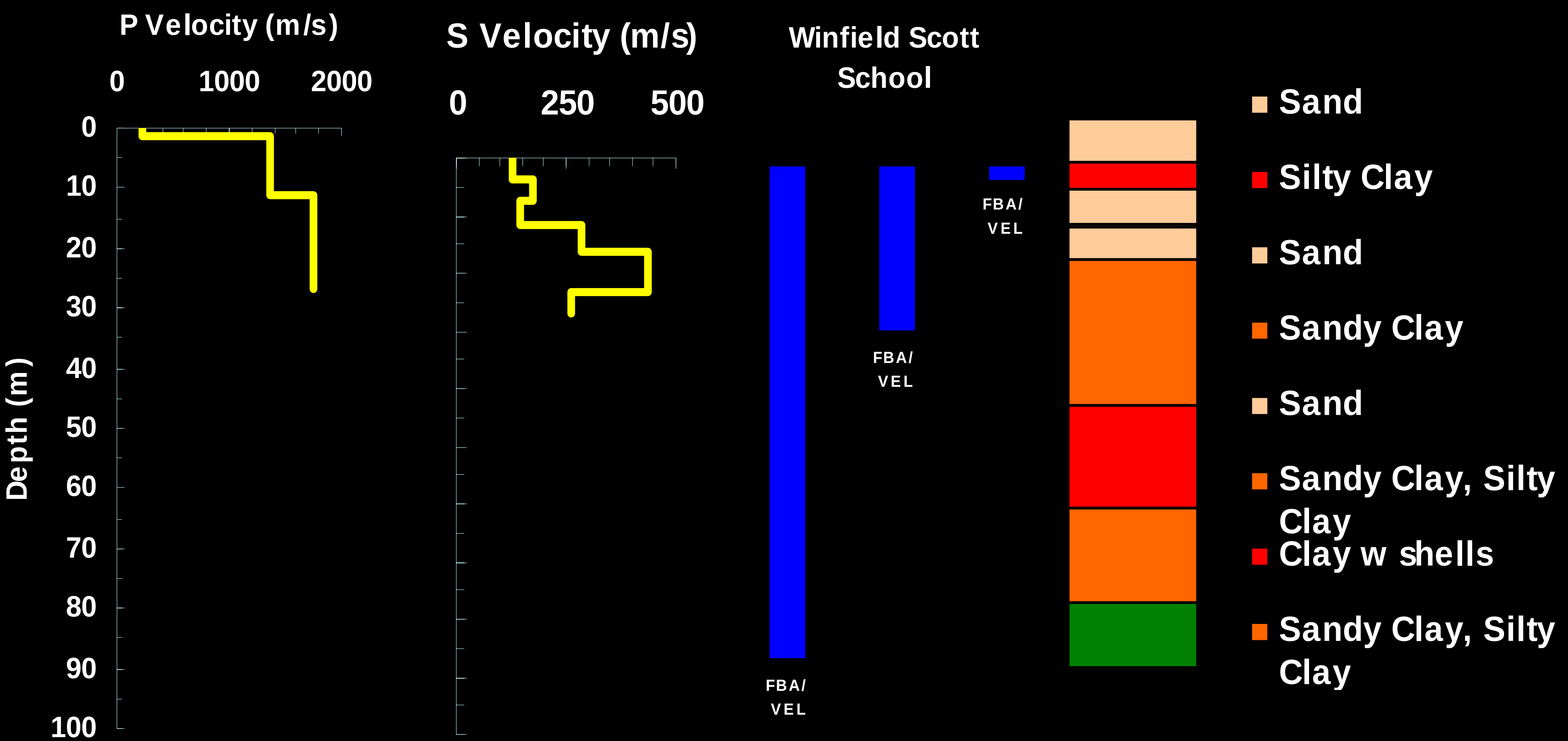
# Seismic and Geologic Logs

## Levi Plaza Borehole Array

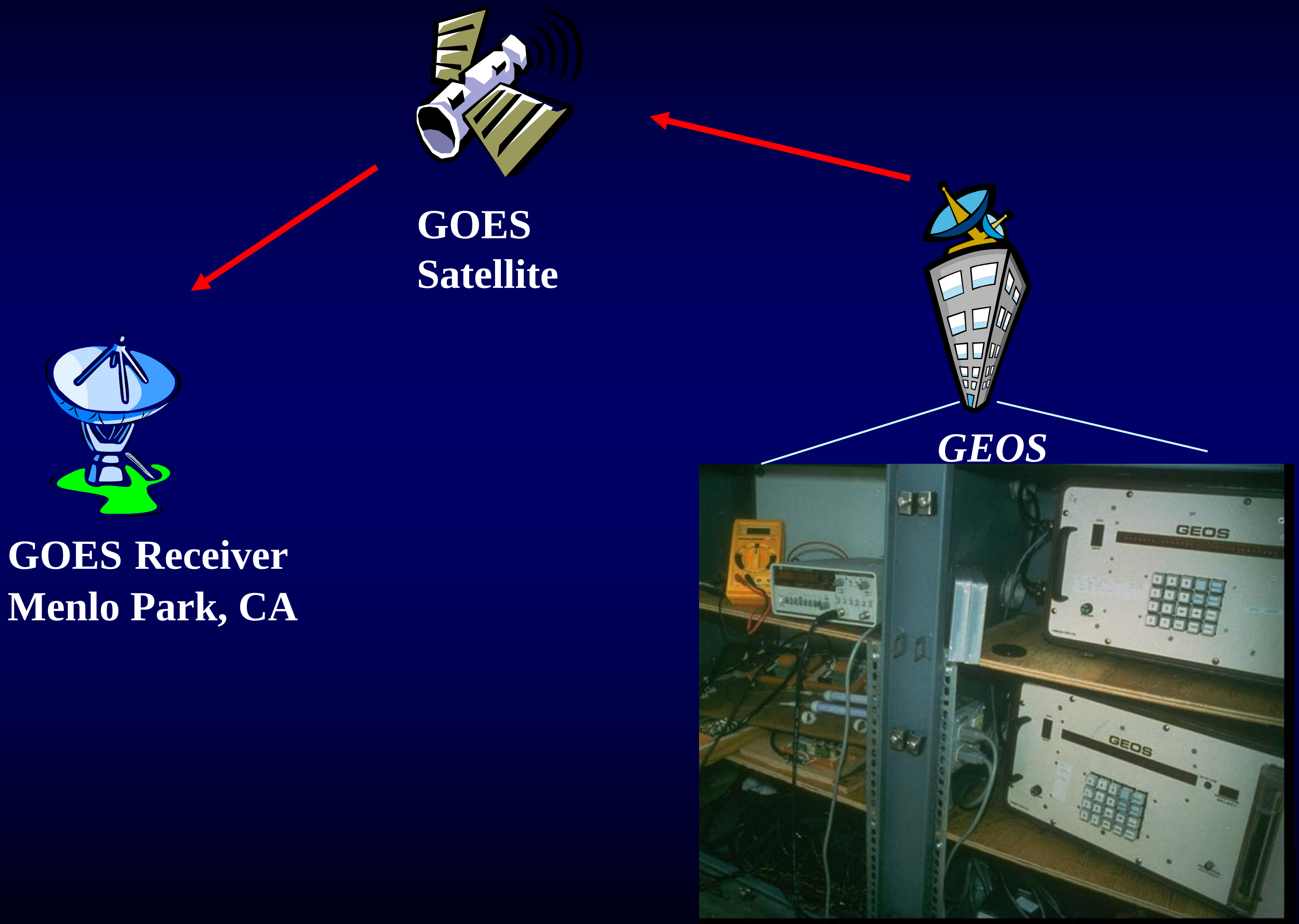


# Locations Near Marina Array in San Francisco, CA

# Seismic and Geologic Logs for Array at Winfield Scott School

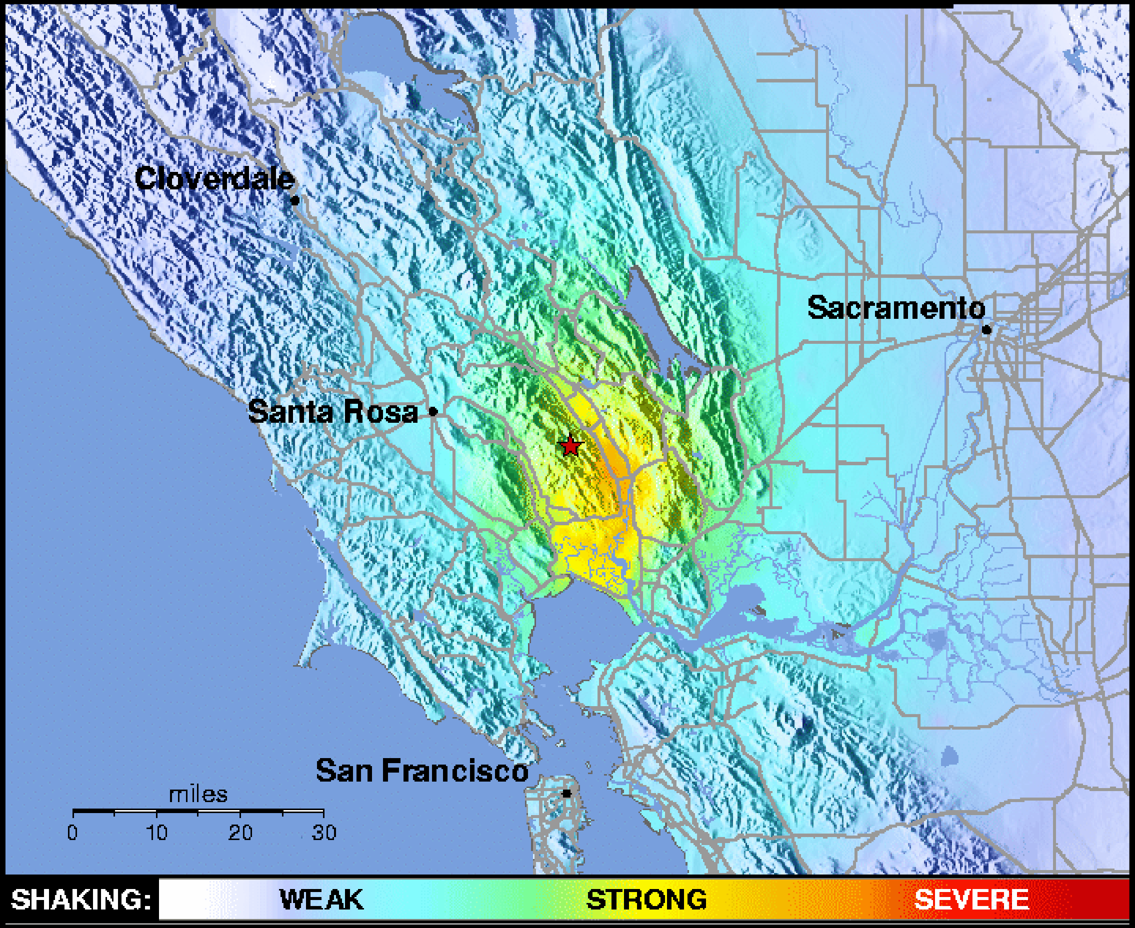


# Instrumentation Configuration

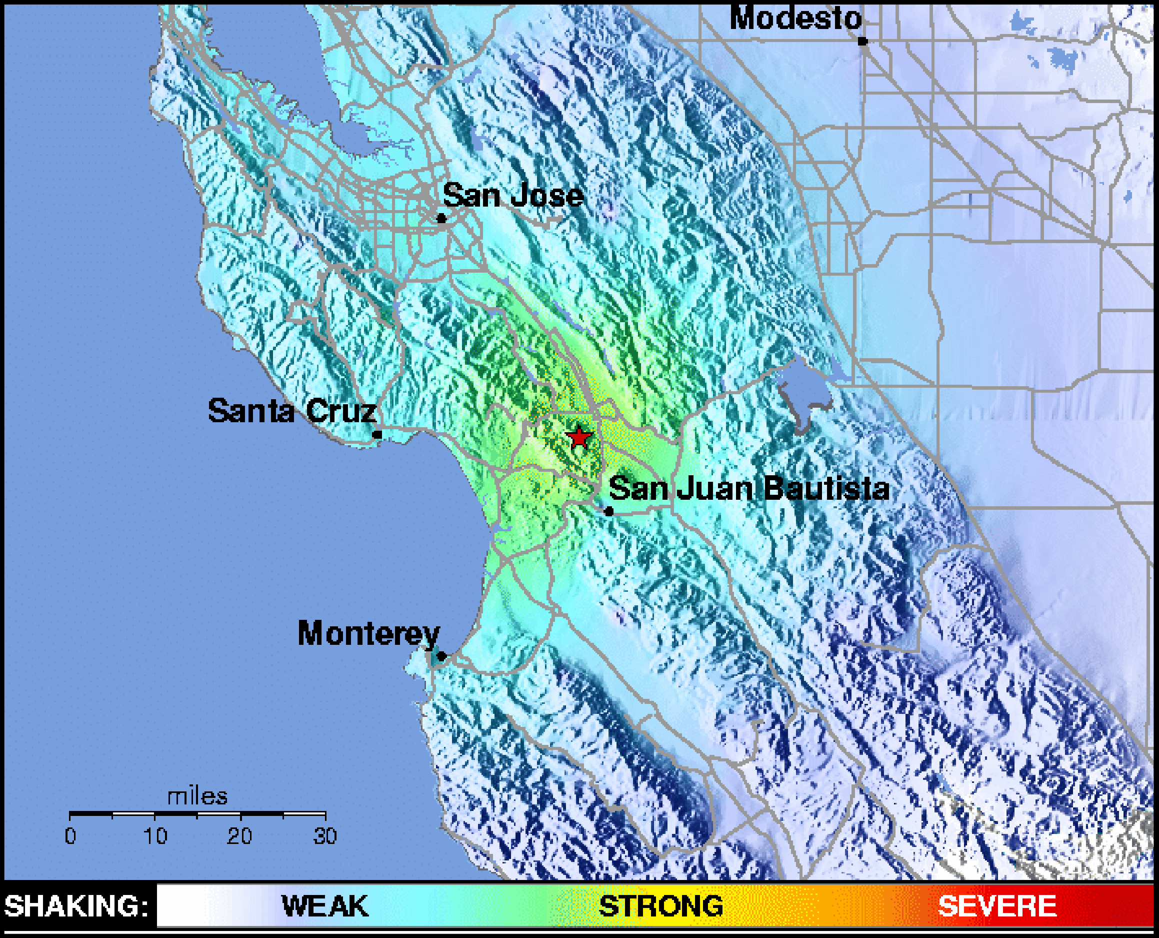


# Epicenter and Shaking Intensity

## Yountville, CA Earthquake, M=5.1

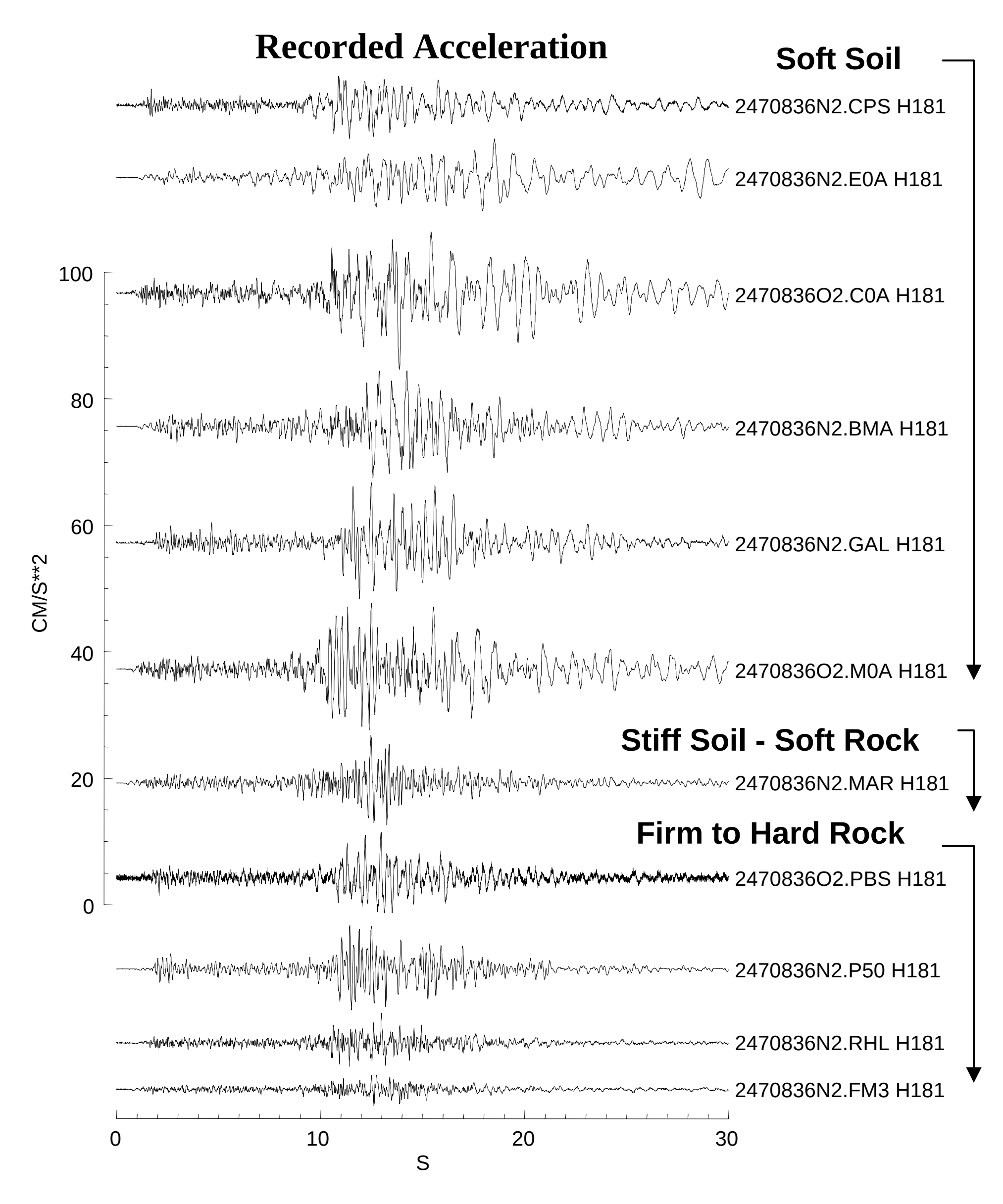


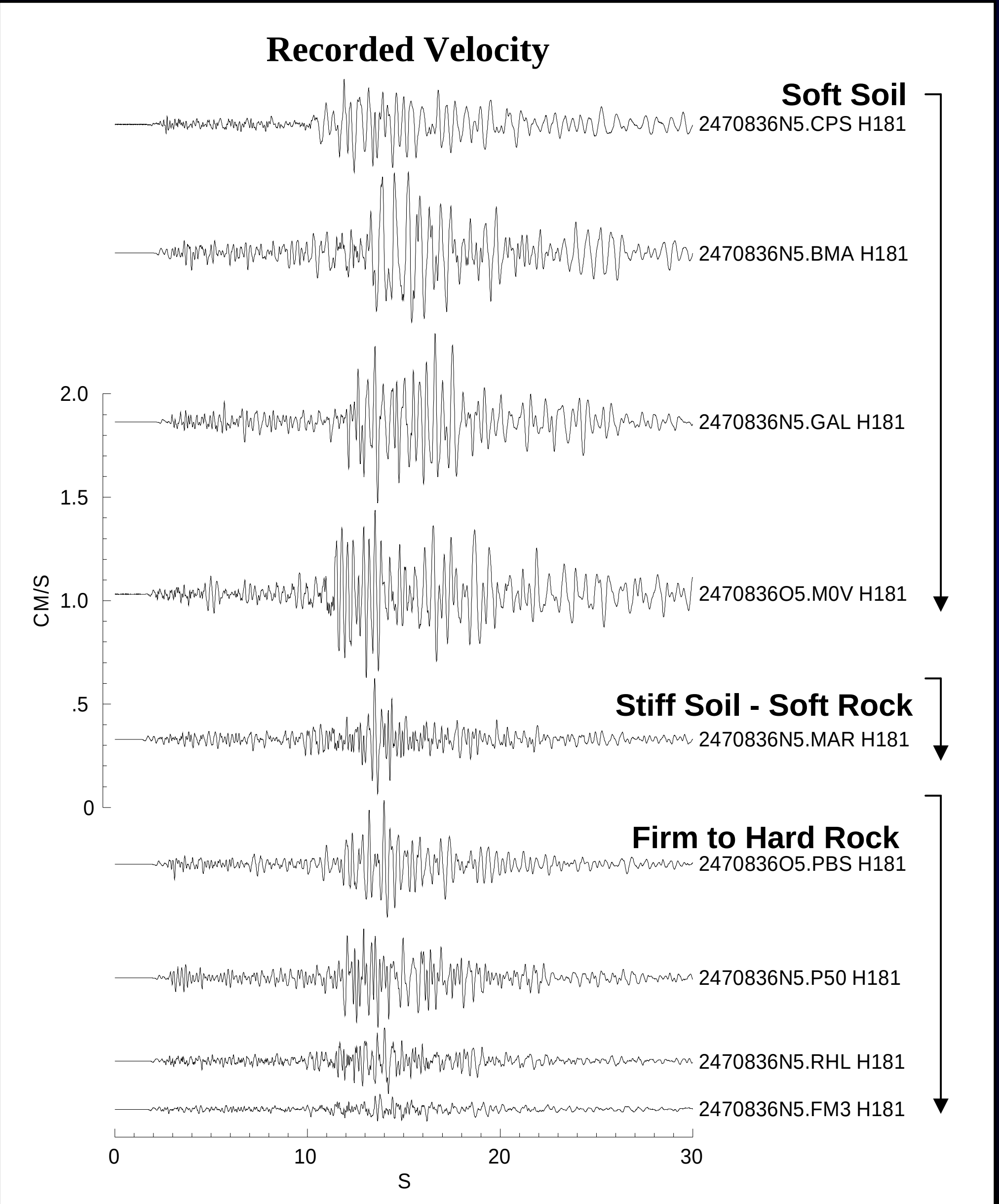
# Epicenter and Shaking Intensity
## Gilroy, CA Earthquake, M=4.9



# Simultaneous Surface Recordings of Radial Acceleration and Velocity

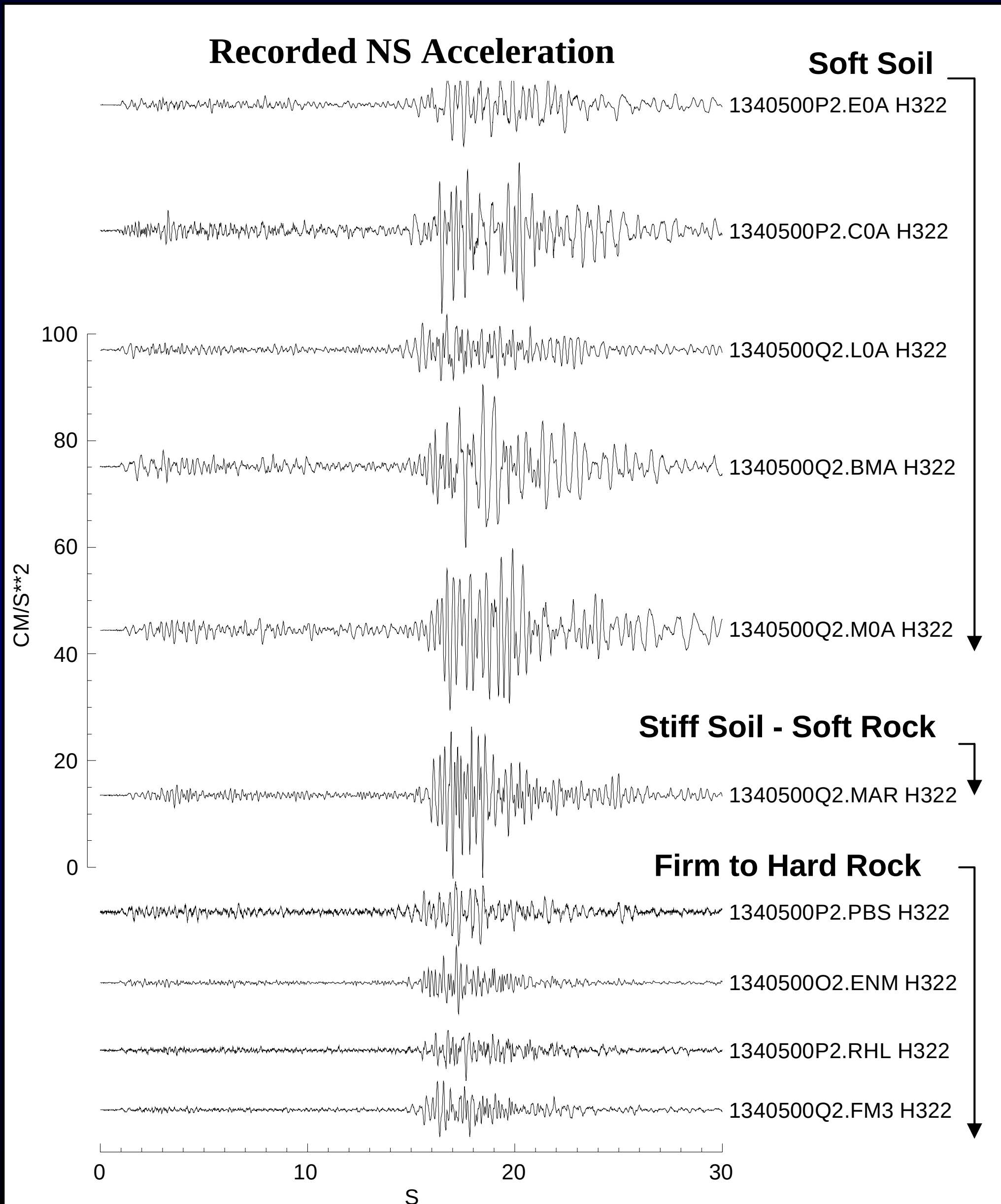
## Yountville Earthquake, M=5.1

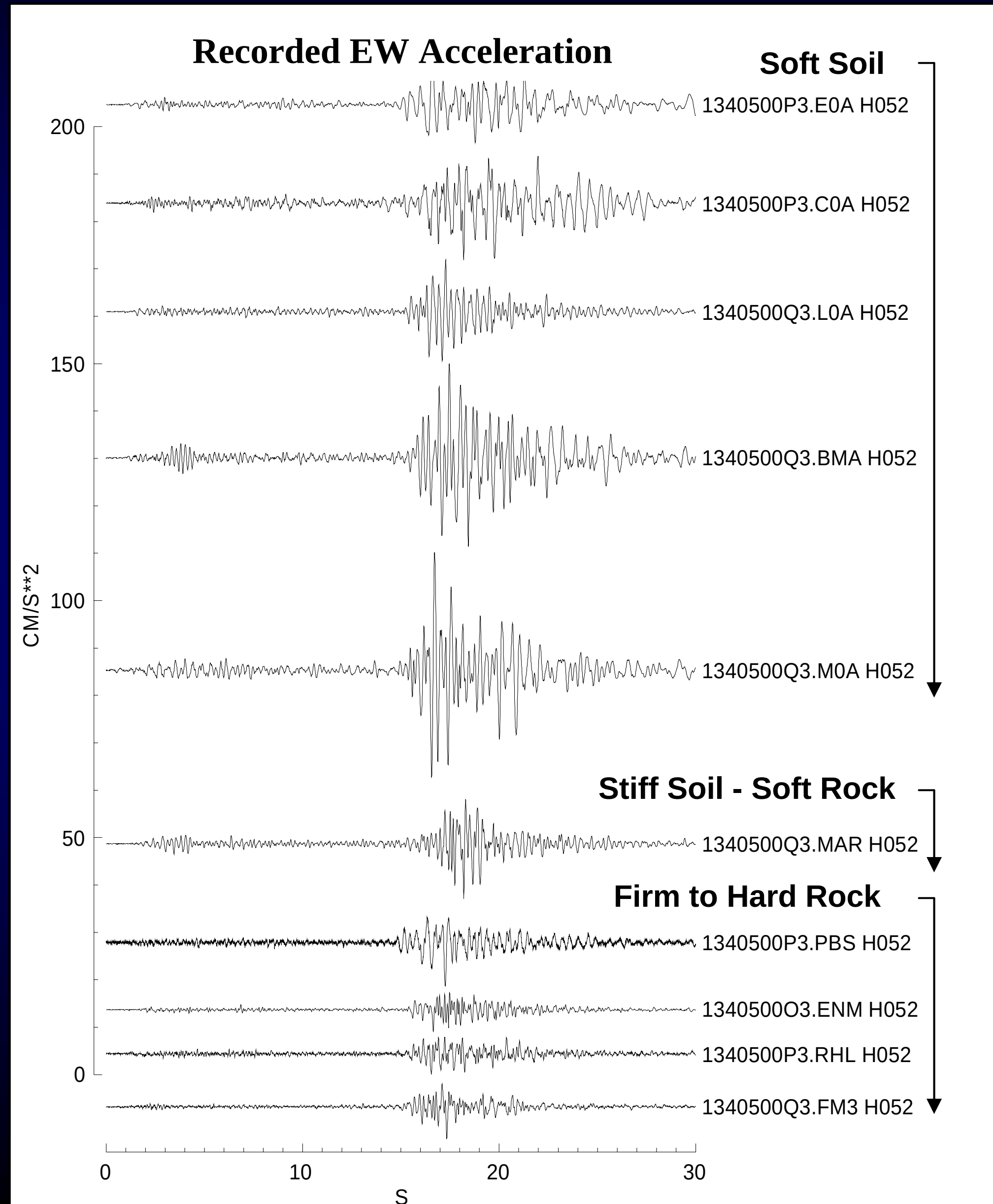


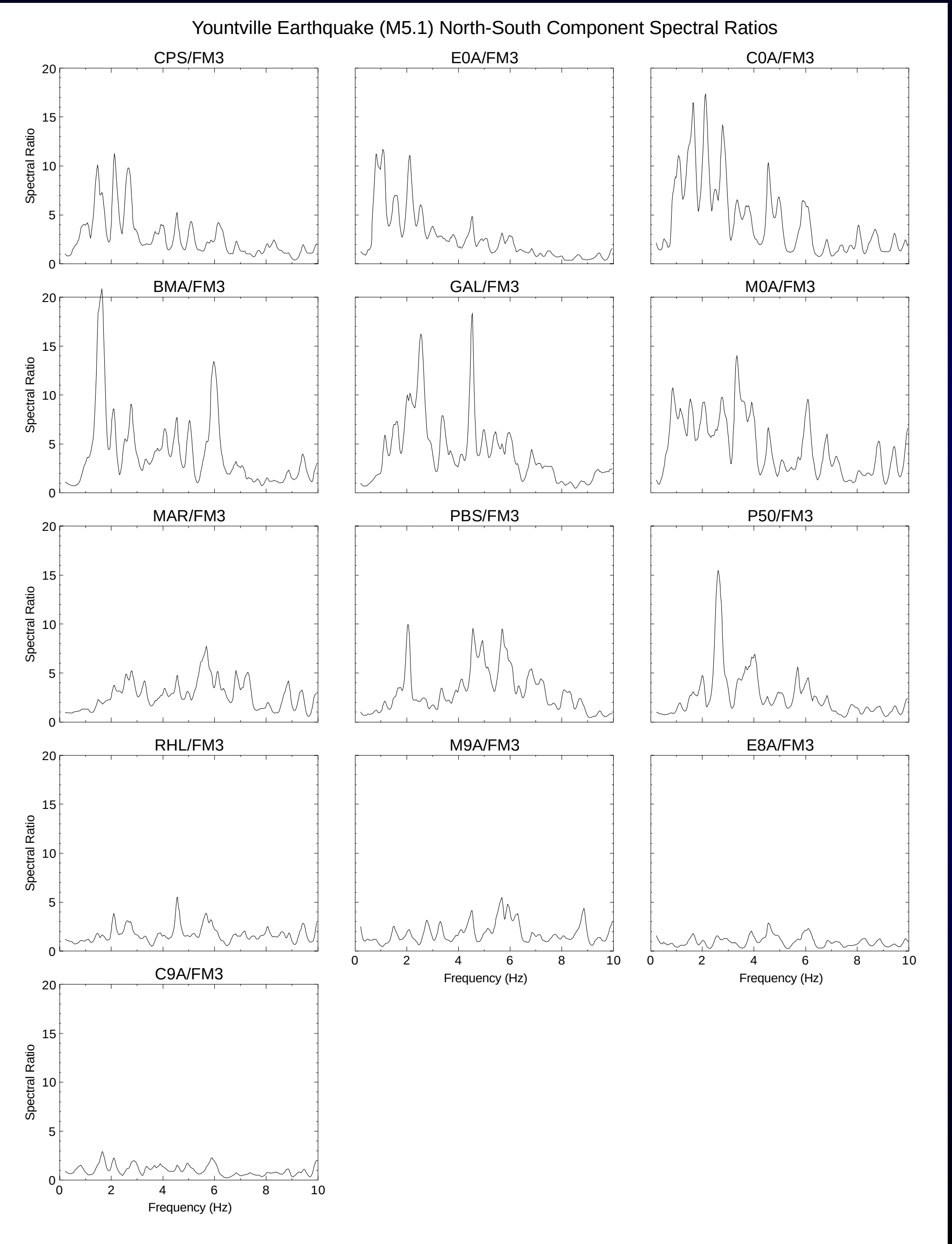
# Surface Recordings of NS & EW Acceleration

## Gilroy Earthquake, M=4.9



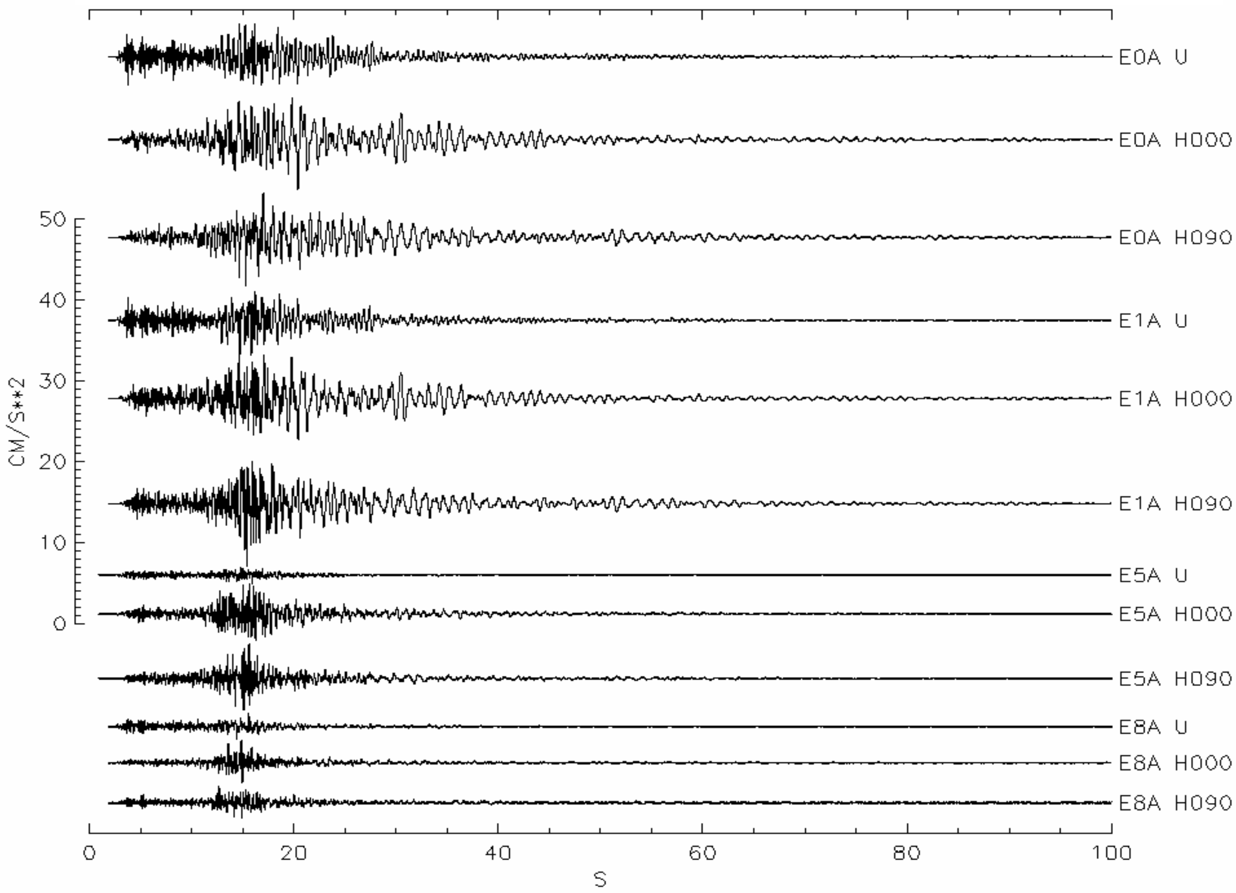



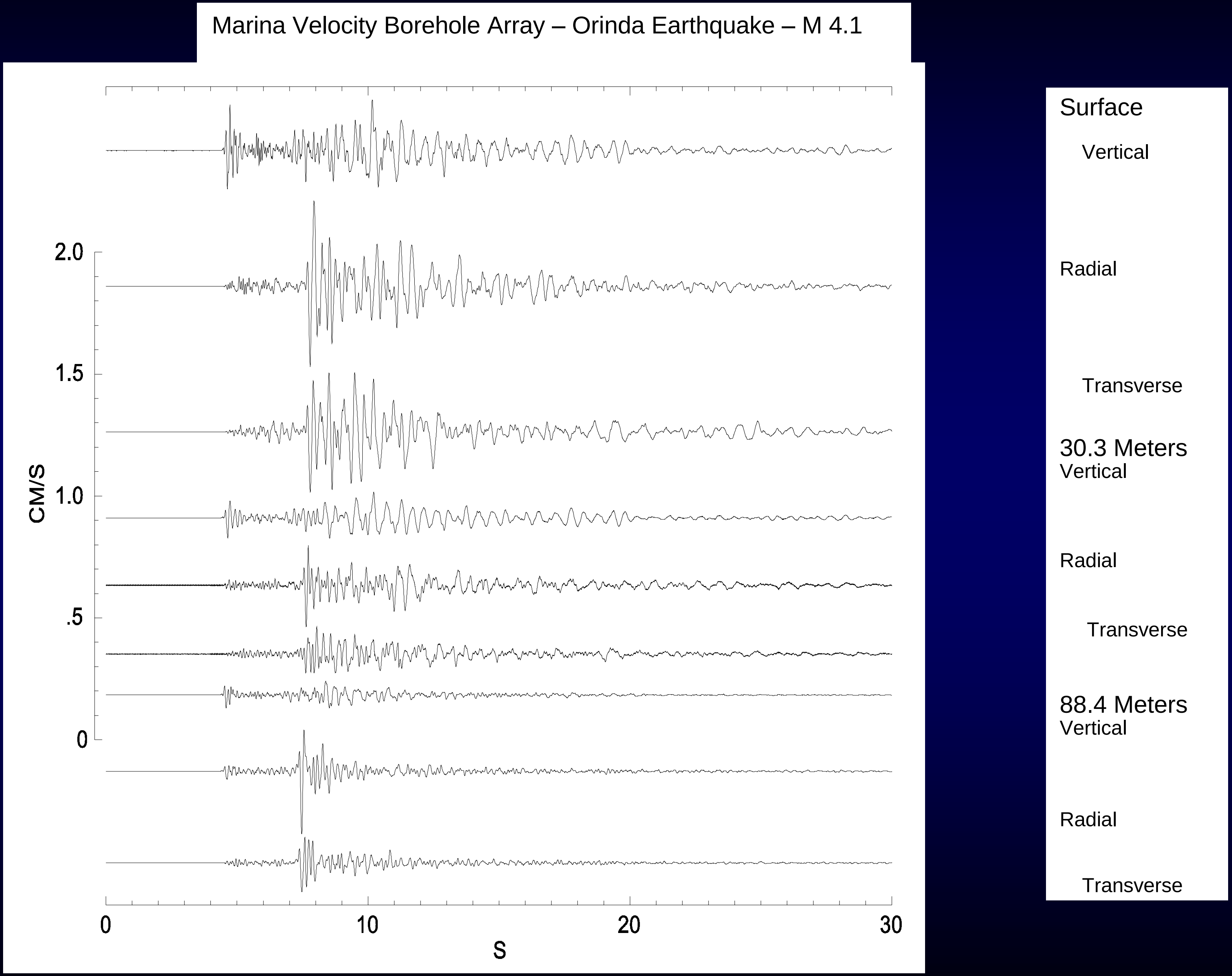
# Amplitude Spectral Ratio to Surface Rock (FM3- Radial -Yountville)



# Embarcadero Plaza

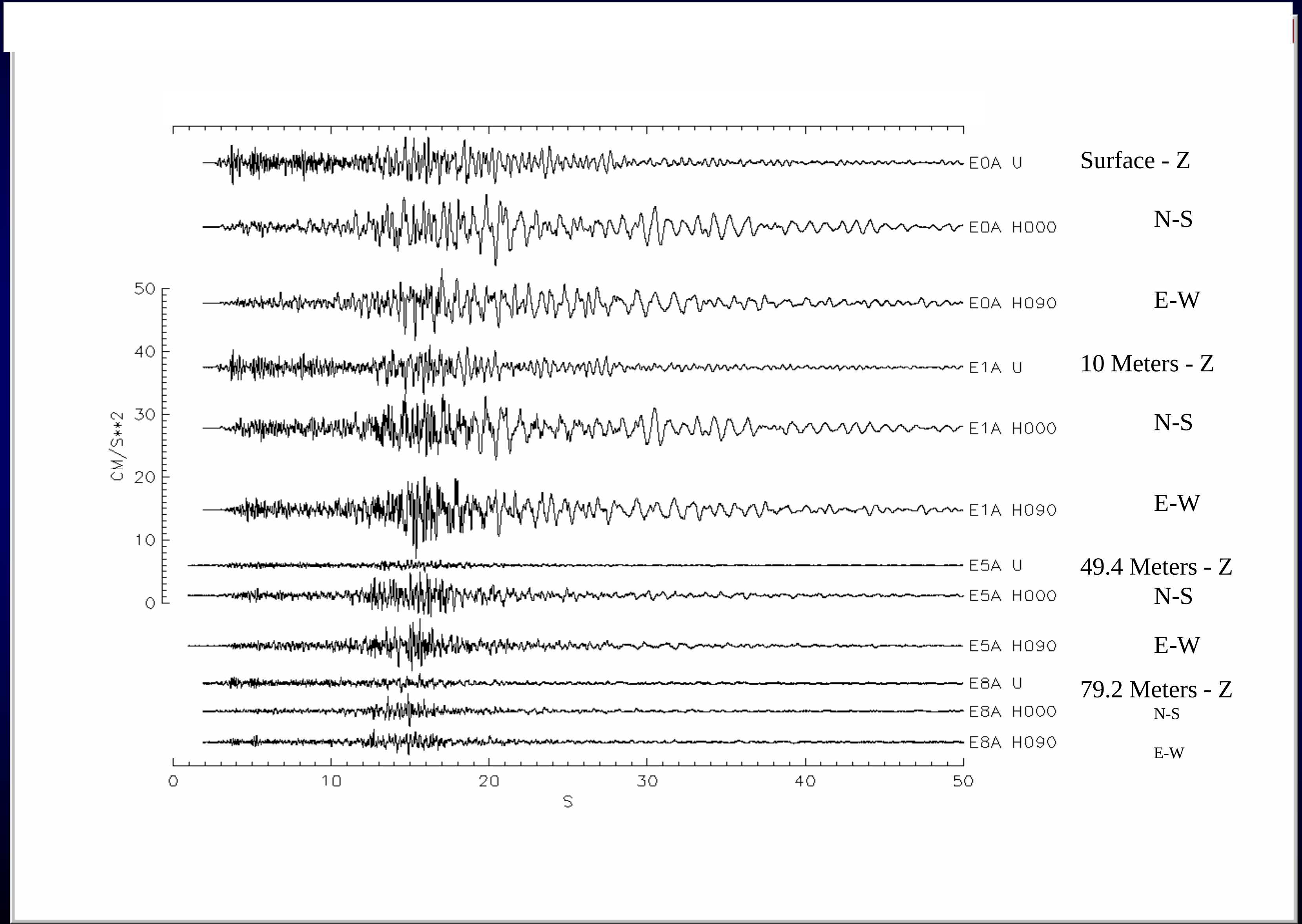
**Yountville Earthquake, M=5.1, 100 seconds**

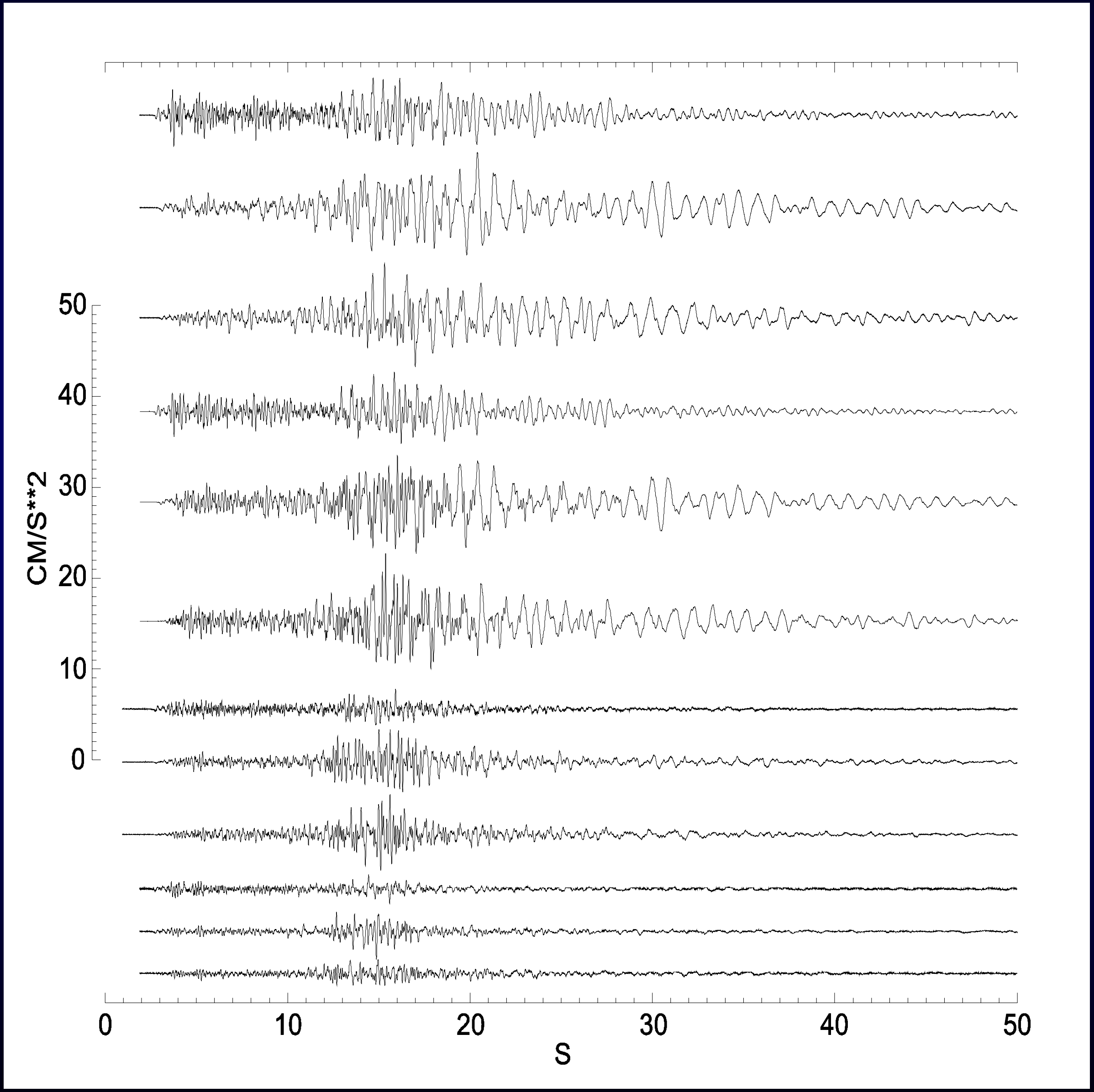



Marina Velocity Borehole Array – Orinda Earthquake – M 4.1
2.0
1.5
1.0
.5
0
CM/S
0
10
20
30
S
Surface
Vertical
Radial
Transverse
30.3 Meters
Vertical
Radial
Transverse
88.4 Meters
Vertical
Radial
Transverse

# Embarcadero Plaza

**Yountville Earthquake, M=5.1, 50 seconds**

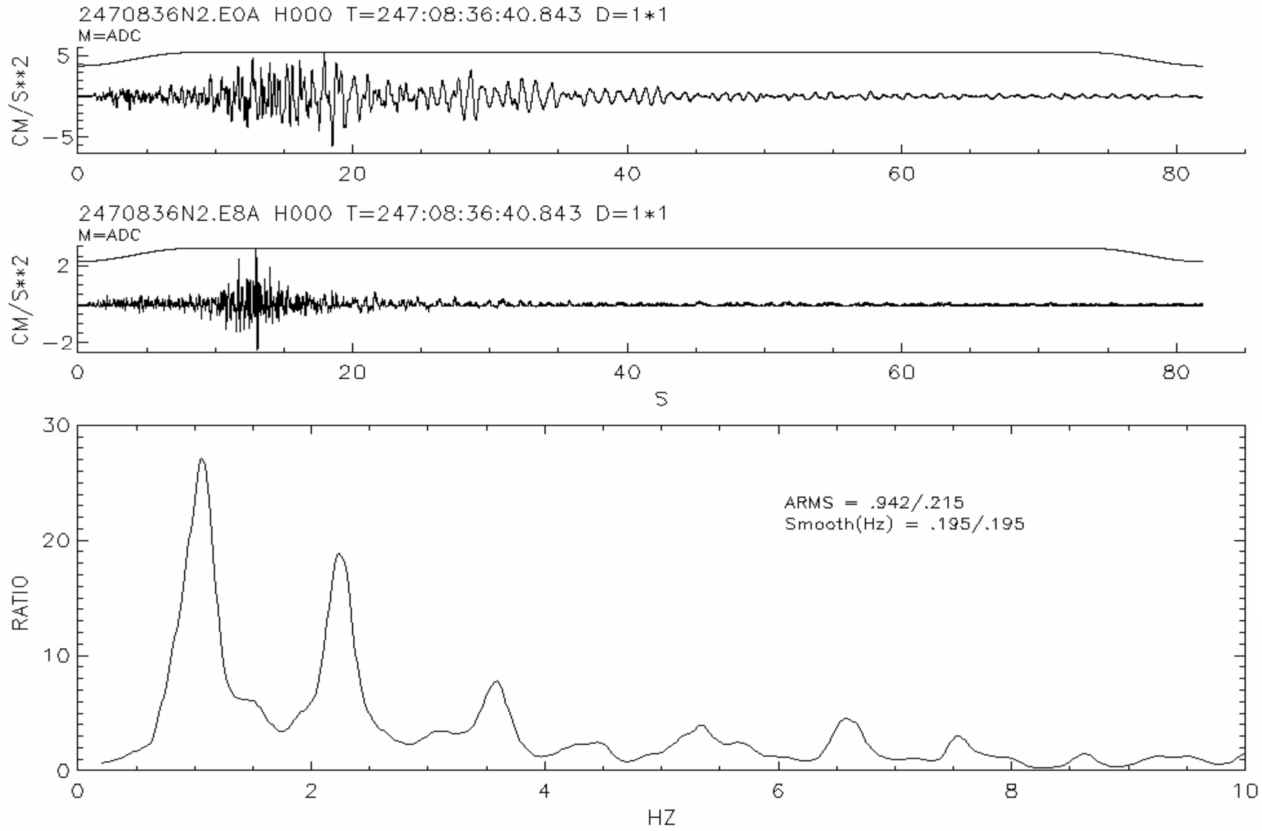




CM/S**2
0
10
20
30
40
50
S

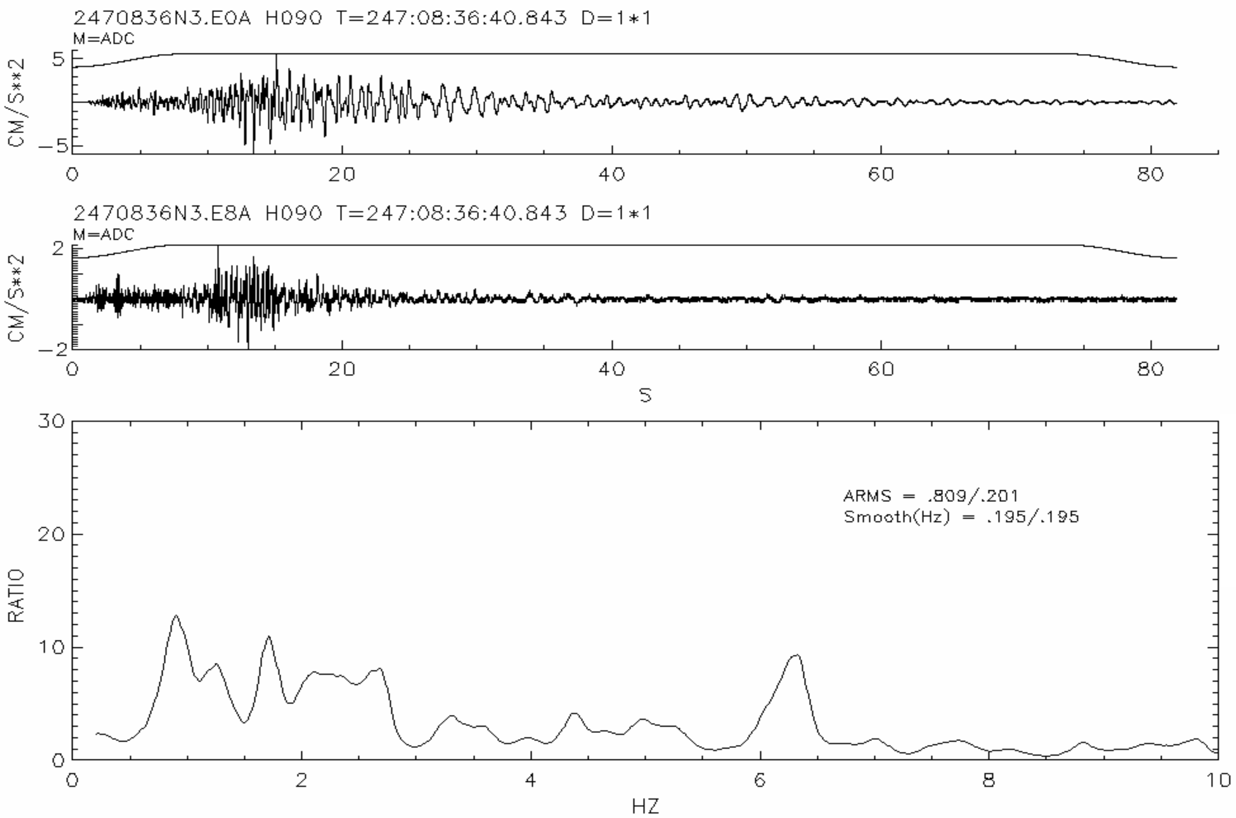
# Embarcadero Plaza Spectral Ratio (Surface NS / 79 Meters NS)

**Yountville Earthquake, M=5.1**



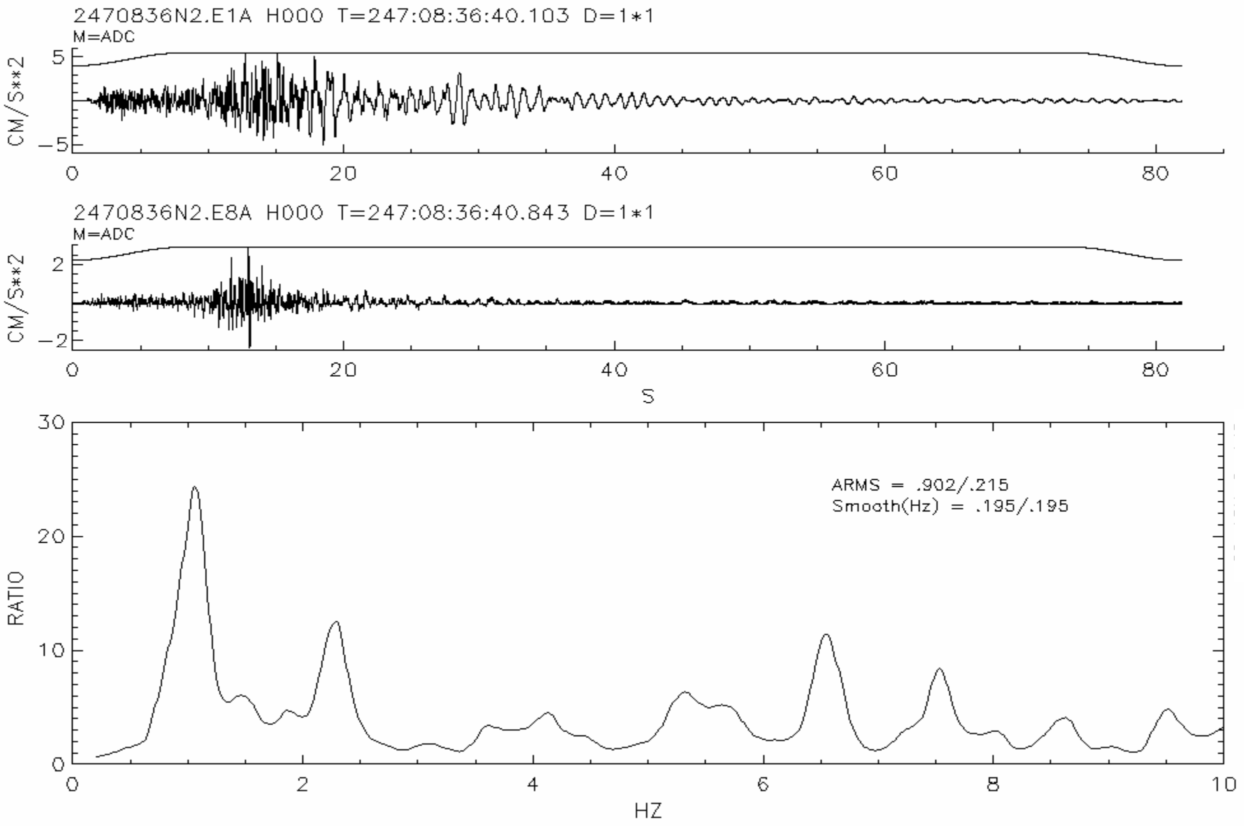
# Embarcadero Plaza Spectral Ratio (Surface EW / 79 Meters EW)

**Yountville Earthquake, M=5.1**



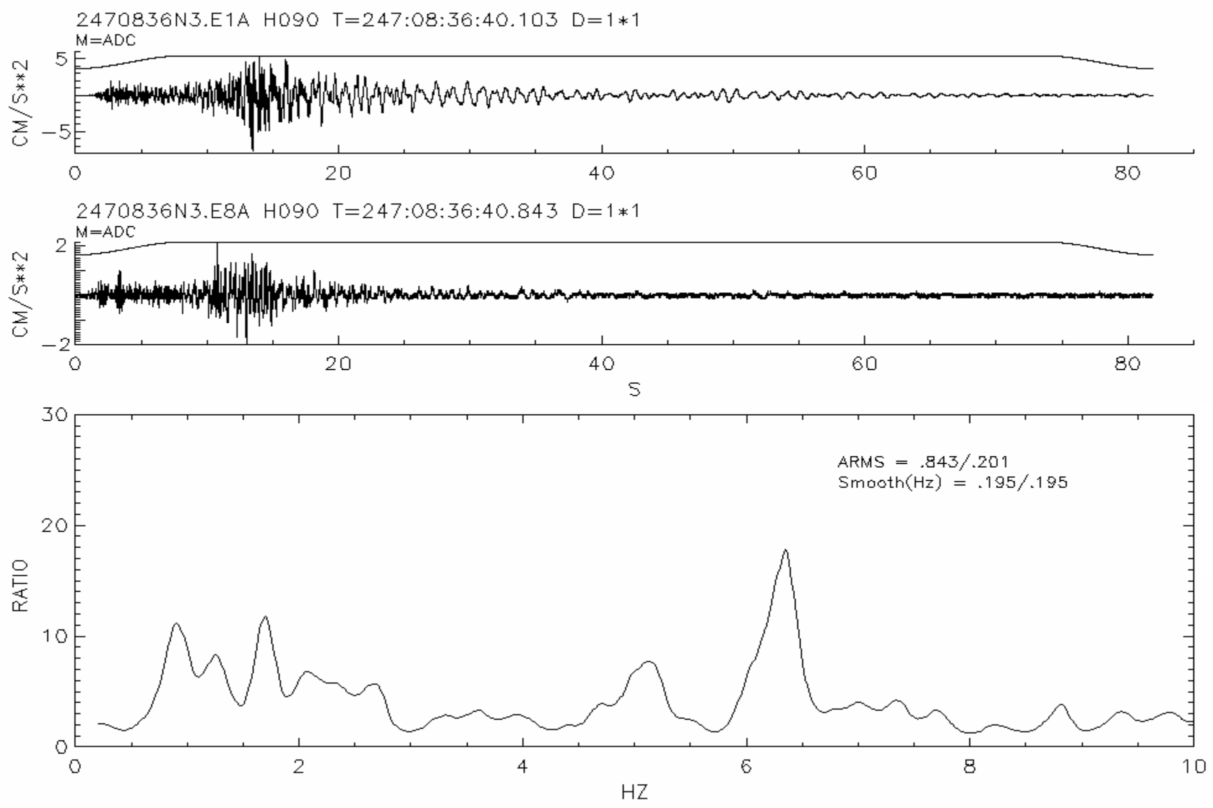
# Embarcadero Plaza Spectral Ratio (10Meters NS / 79 Meters NS)

**Yountville Earthquake, M=5.1**



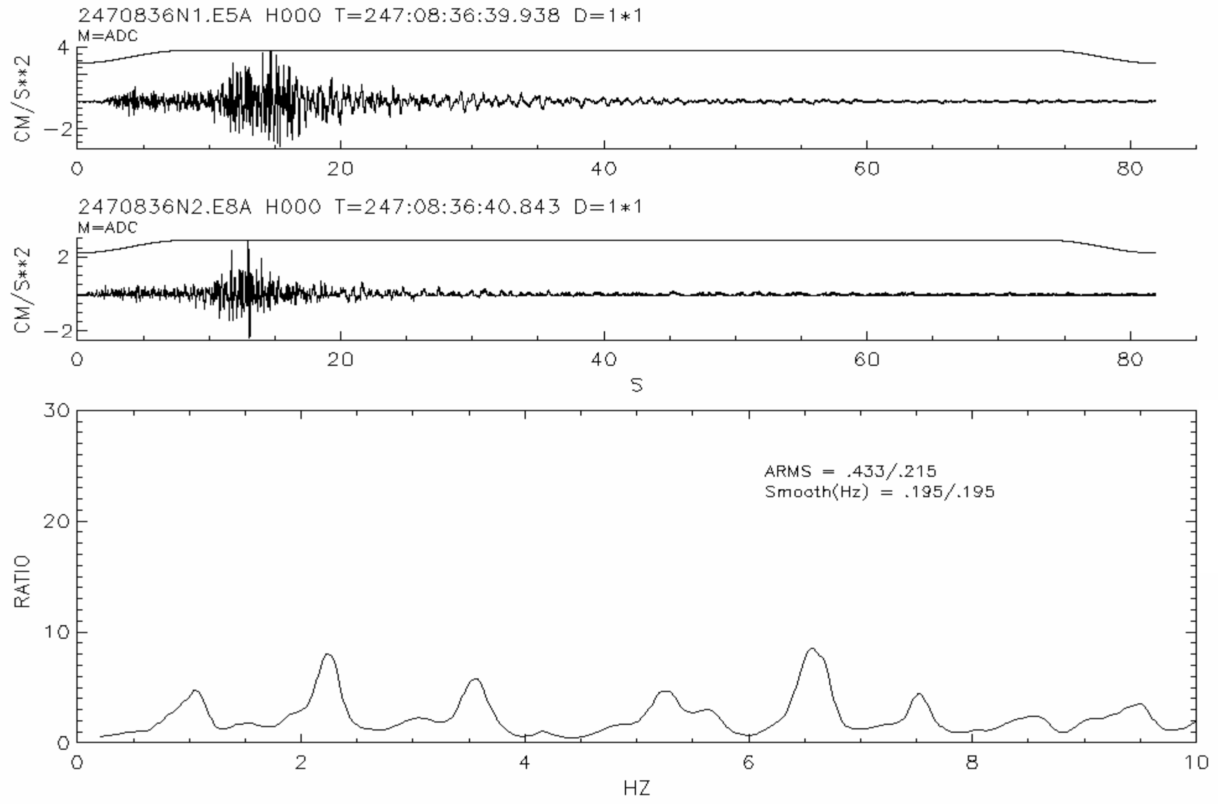
# Embarcadero Plaza Spectral Ratio (10Meters EW / 79 Meters EW)

**Yountville Earthquake, M=5.1**



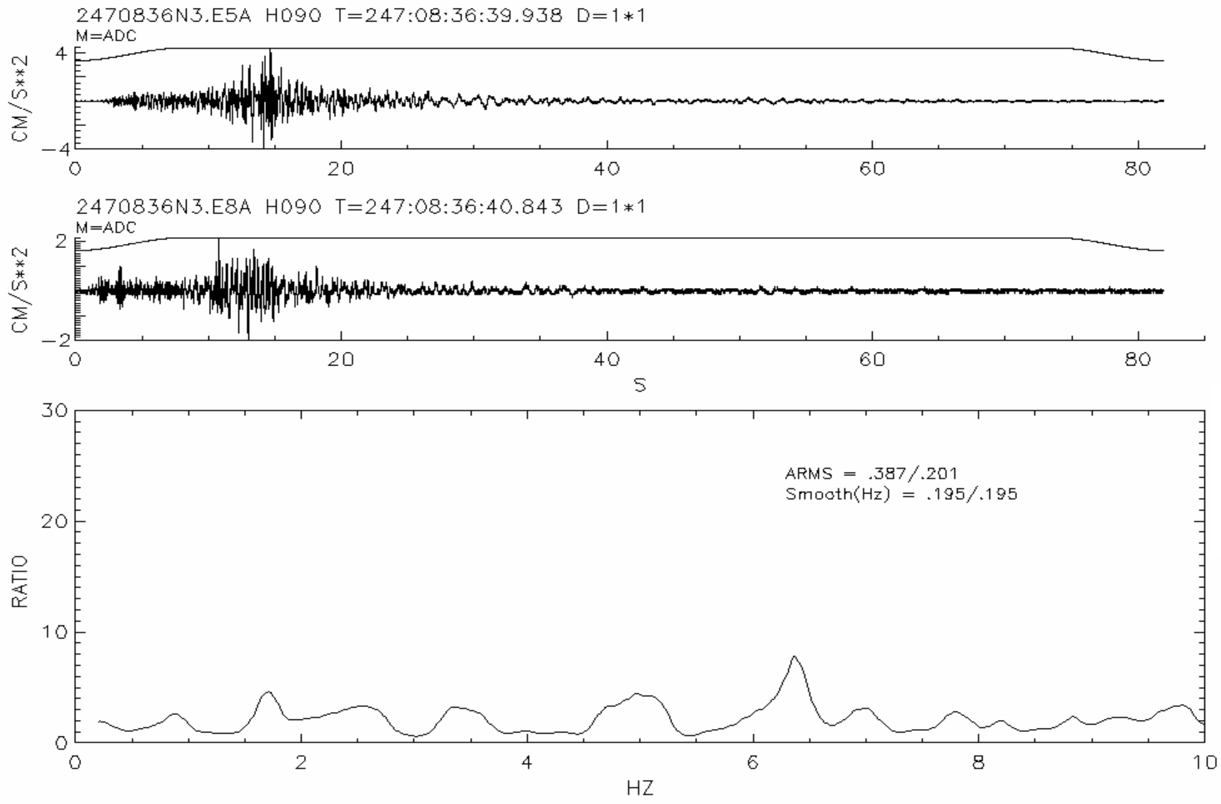
# Embarcadero Plaza Spectral Ratio (50Meters NS / 79 Meters NS)

**Yountville Earthquake, M=5.1**



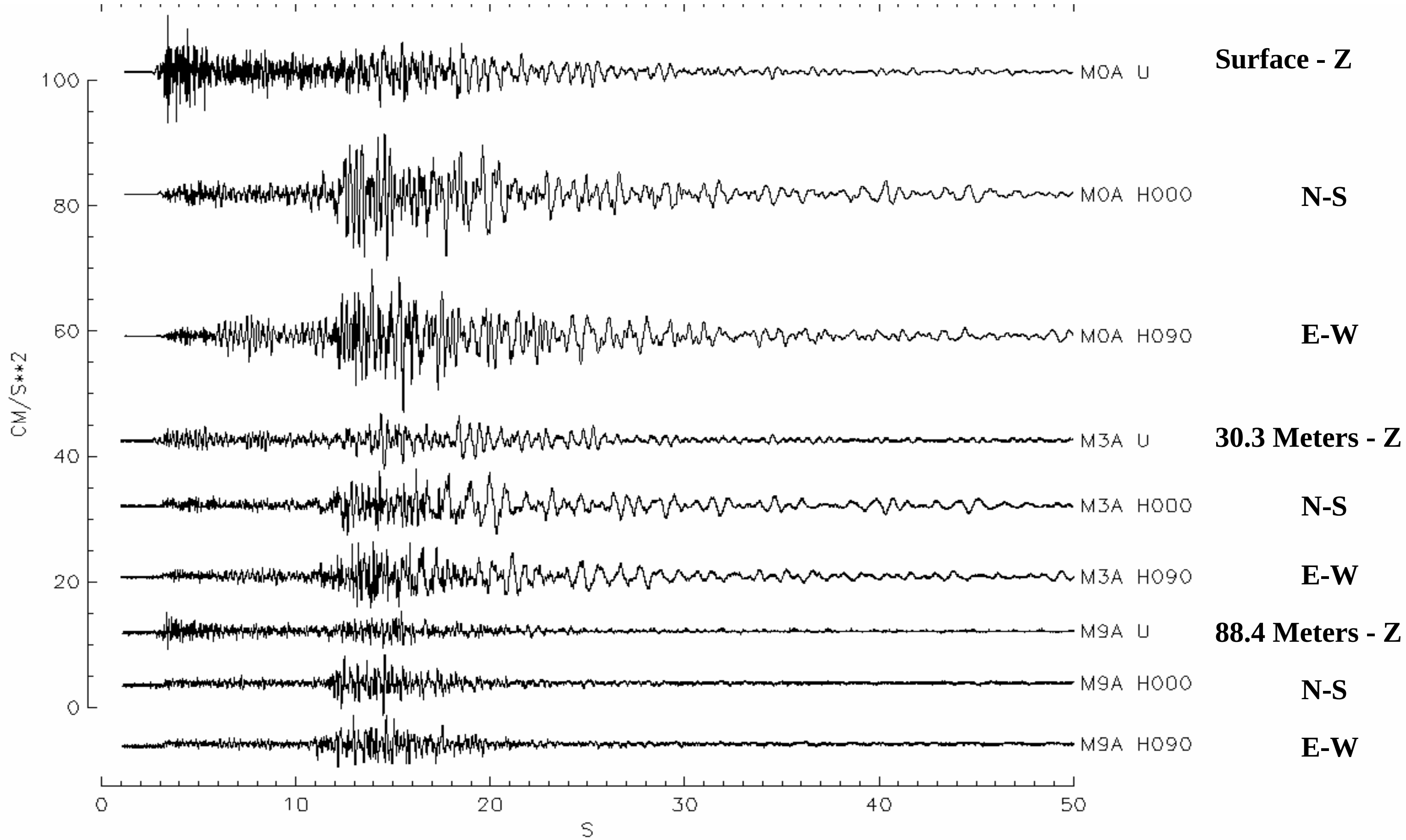
# Embarcadero Plaza Spectral Ratio (50Meters EW / 79 Meters EW)

**Yountville Earthquake, M=5.1**



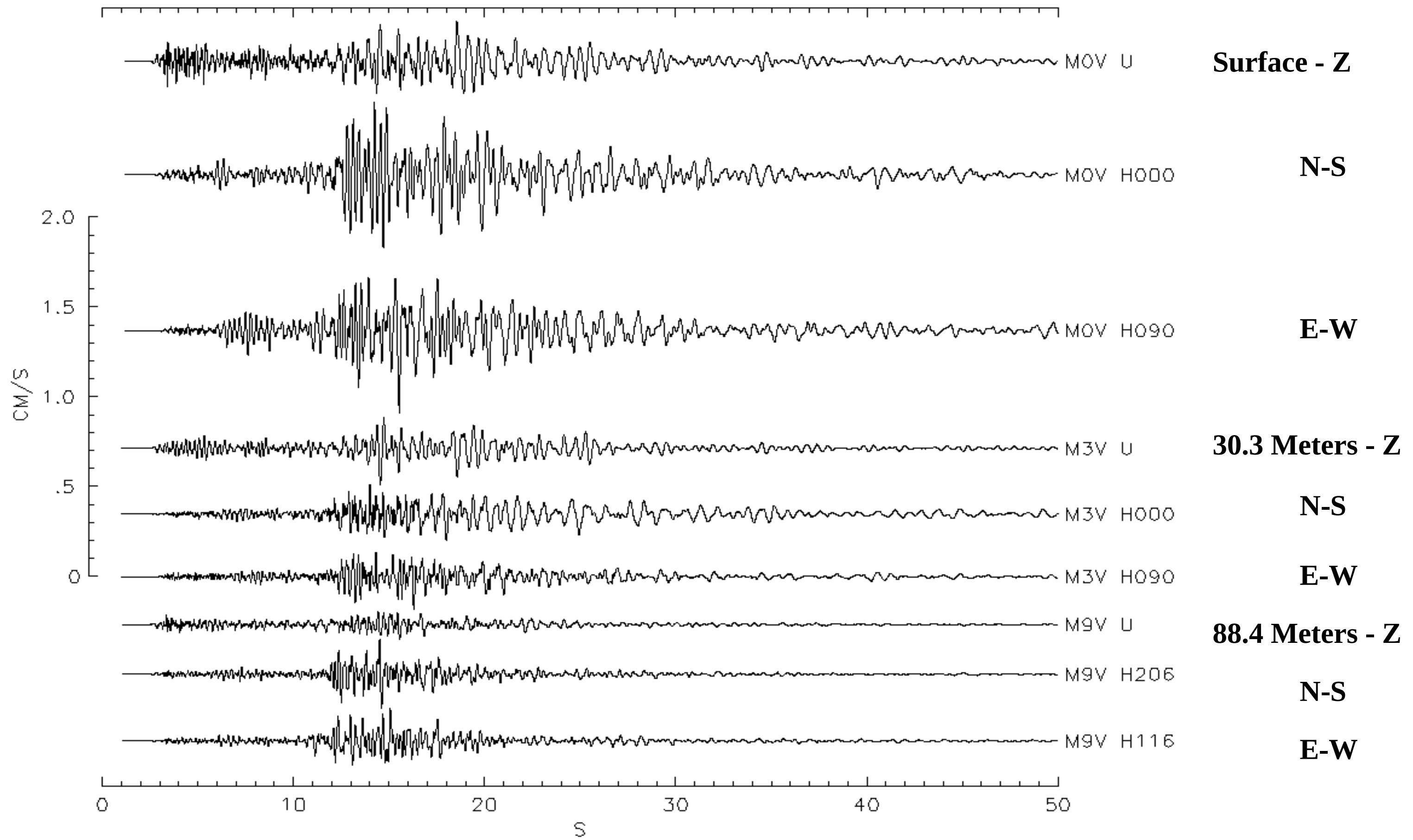
# San Francisco Marina Acceleration

## Yountville Earthquake, M=5.1, 50 seconds



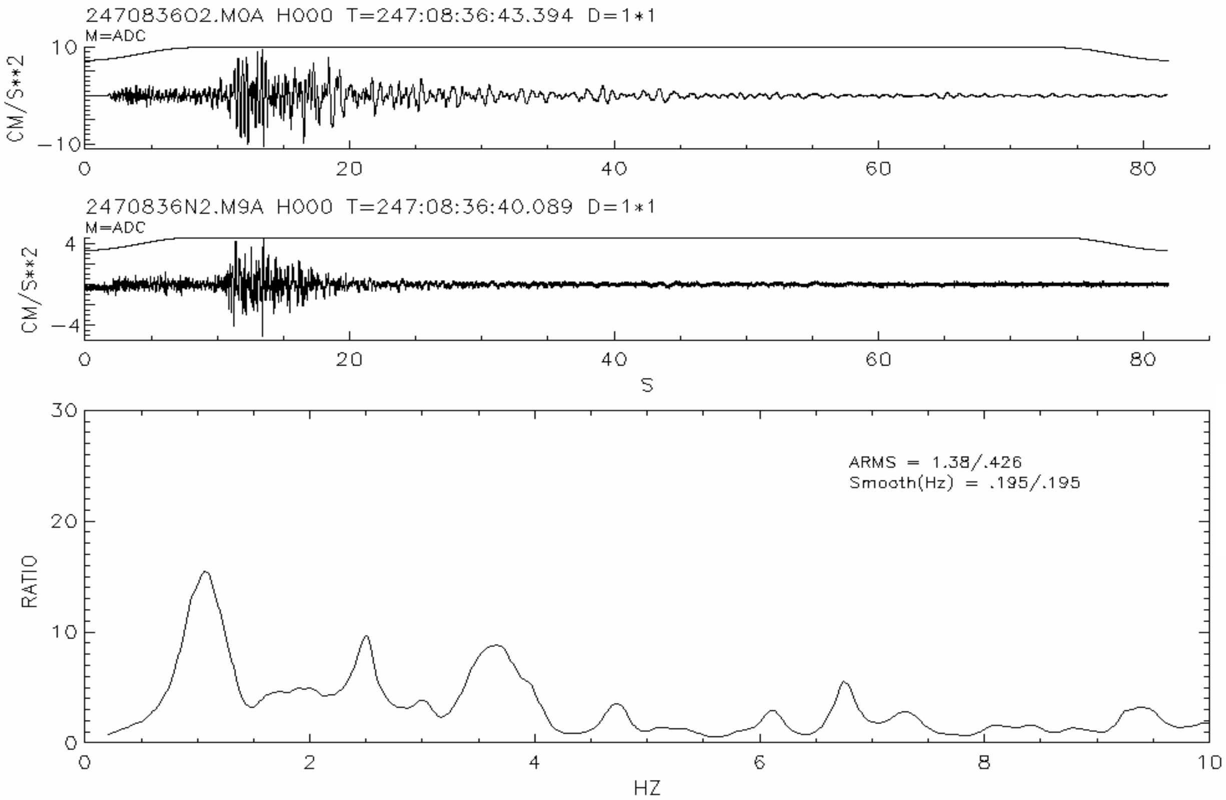
# San Francisco Marina Recorded Velocity

**Yountville Earthquake, M=5.1, 50 seconds**



# San Francisco Marina Spectral Ratio (Surface NS / 88 Meters NS)

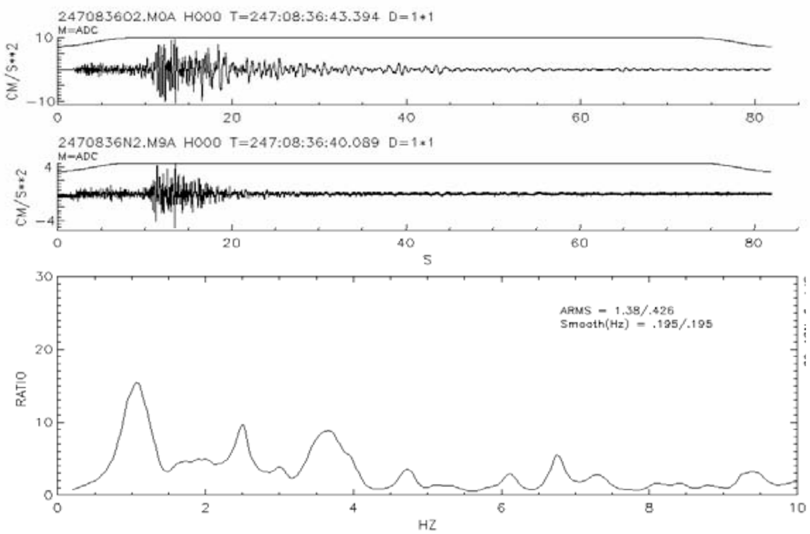
## Yountville Earthquake, M=5.1



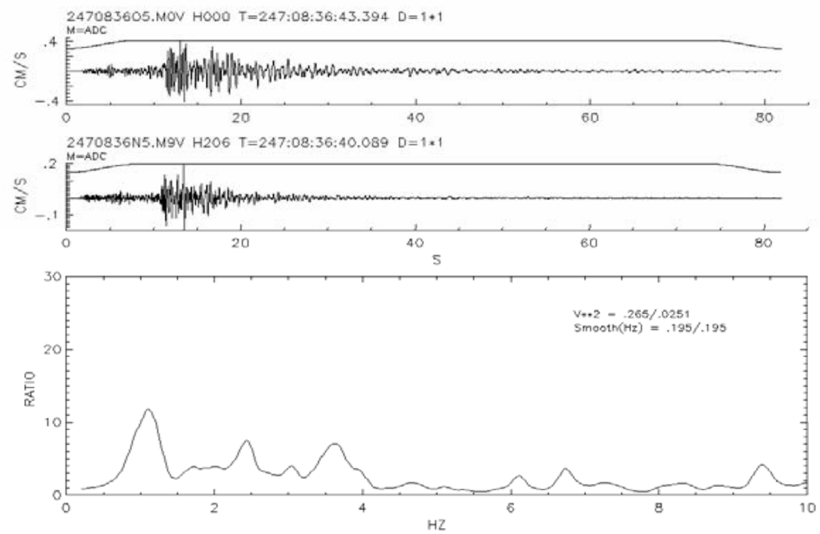
# San Francisco Marina Acceleration and Velocity Spectral Ratios

## Surface NS / 88 Meters NS; Yountville Earthquake, M=5.1

### Ratio of Recorded Acceleration

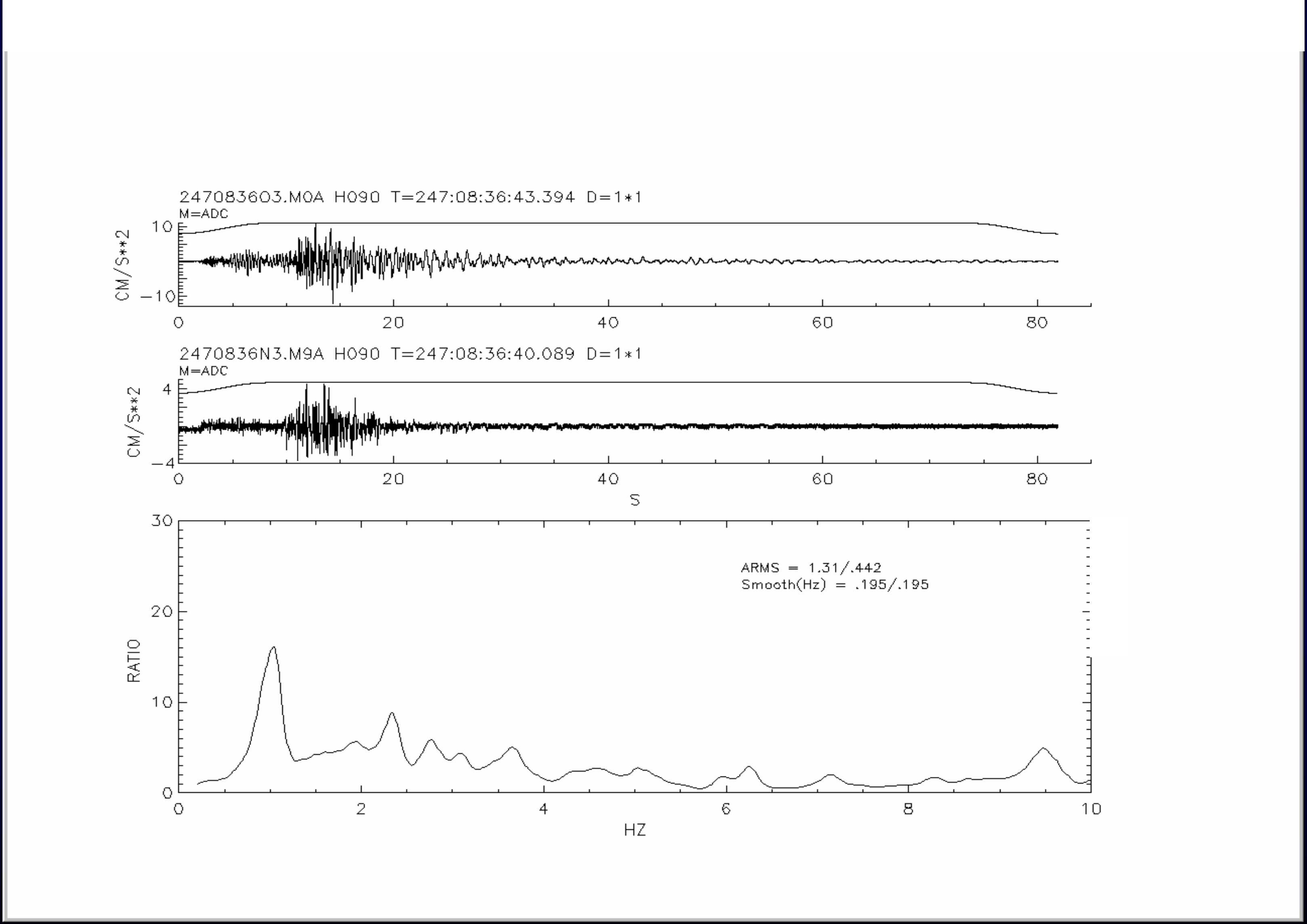



### Ratio of Recorded Velocity



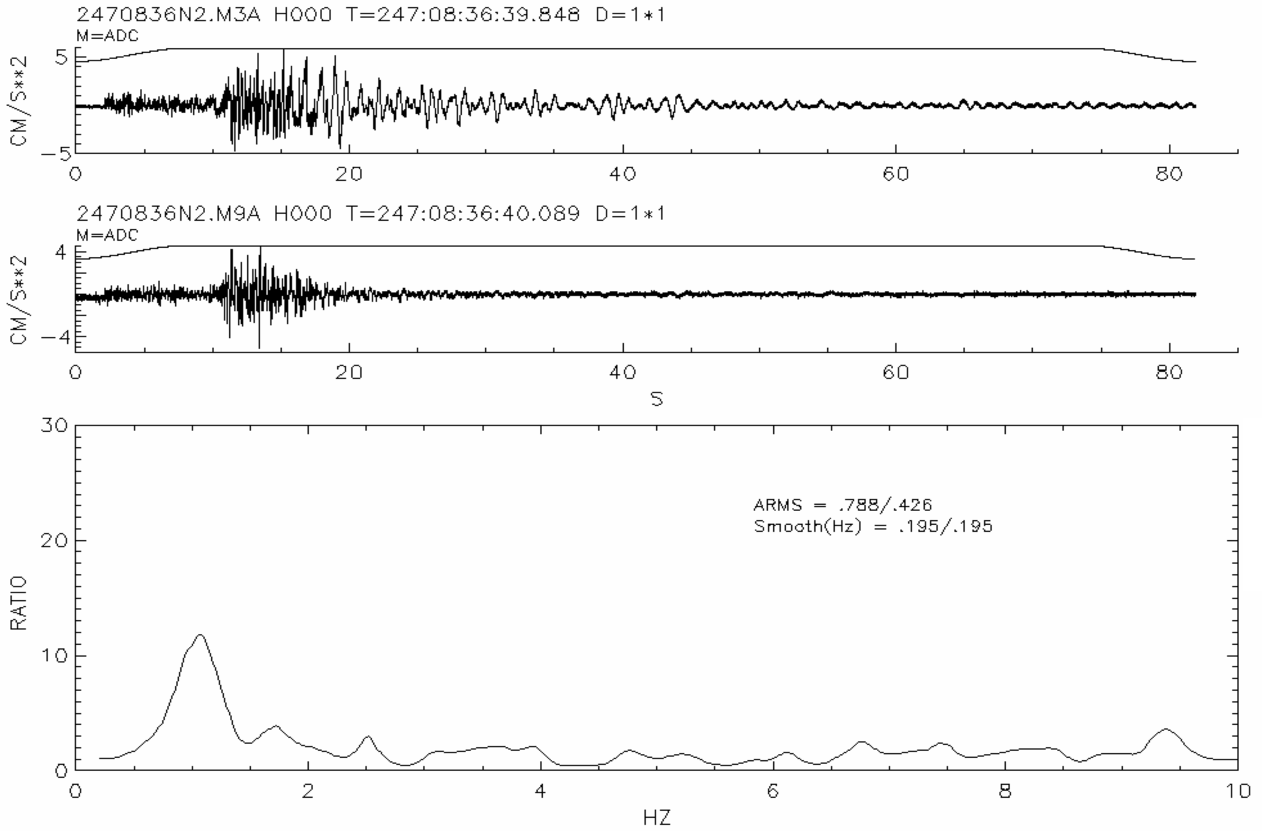
# San Francisco Marina Spectral Ratio (Surface EW / 88 Meters EW)

## Yountville Earthquake, M=5.1



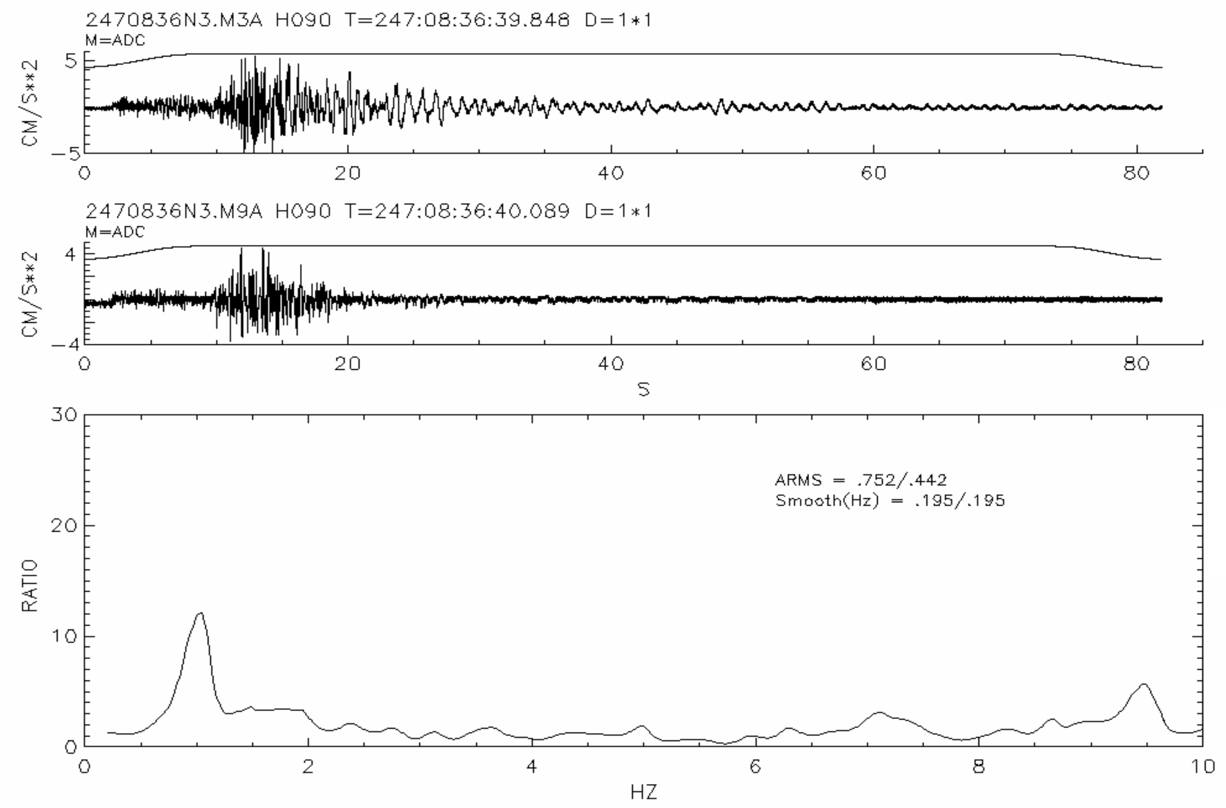
# San Francisco Marina Spectral Ratio (30 Meters NS / 88 Meters NS)

**Yountville Earthquake, M=5.1**



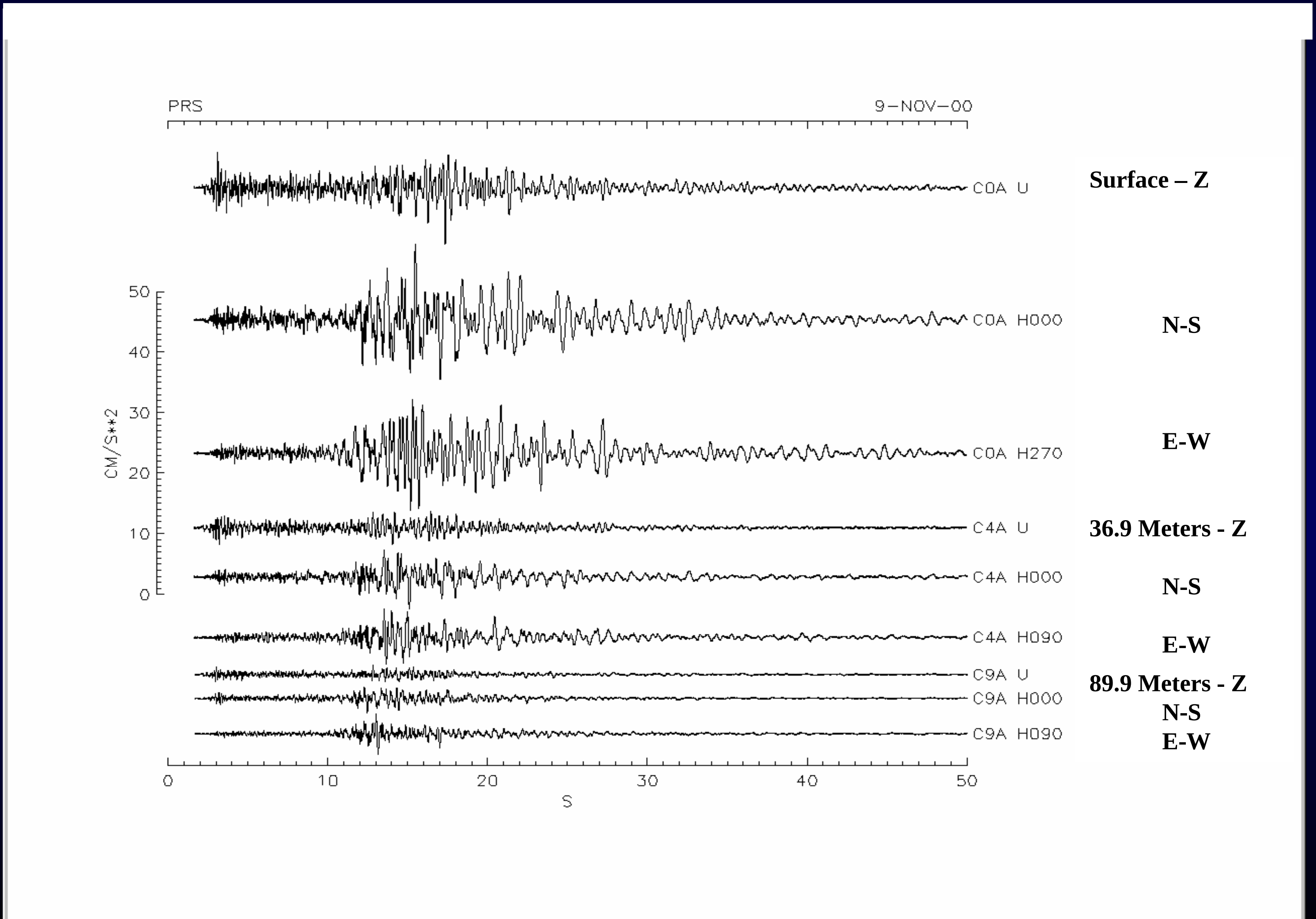
# San Francisco Marina Spectral Ratio (30 Meters EW / 88 Meters EW)

## Yountville Earthquake, M=5.1



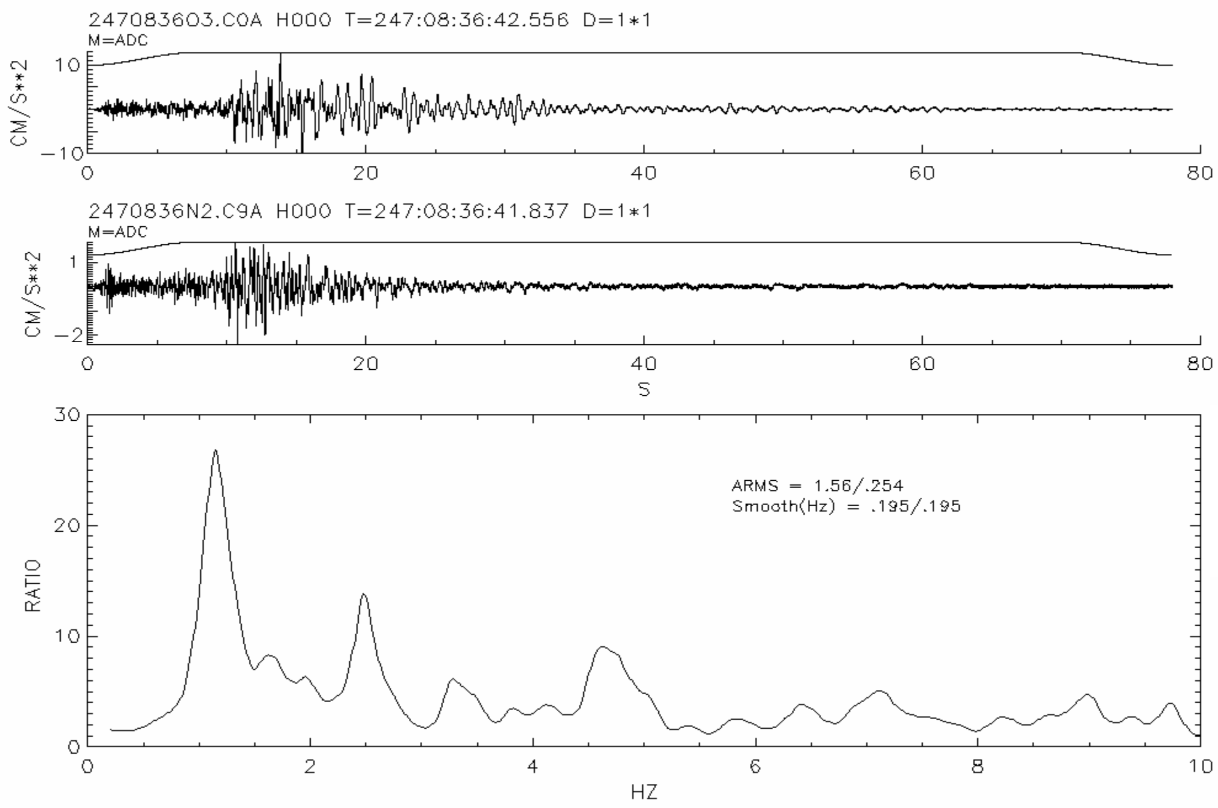
# Bessie Carmichael School Acceleration

## Yountville Earthquake, M=5.1, 50 seconds



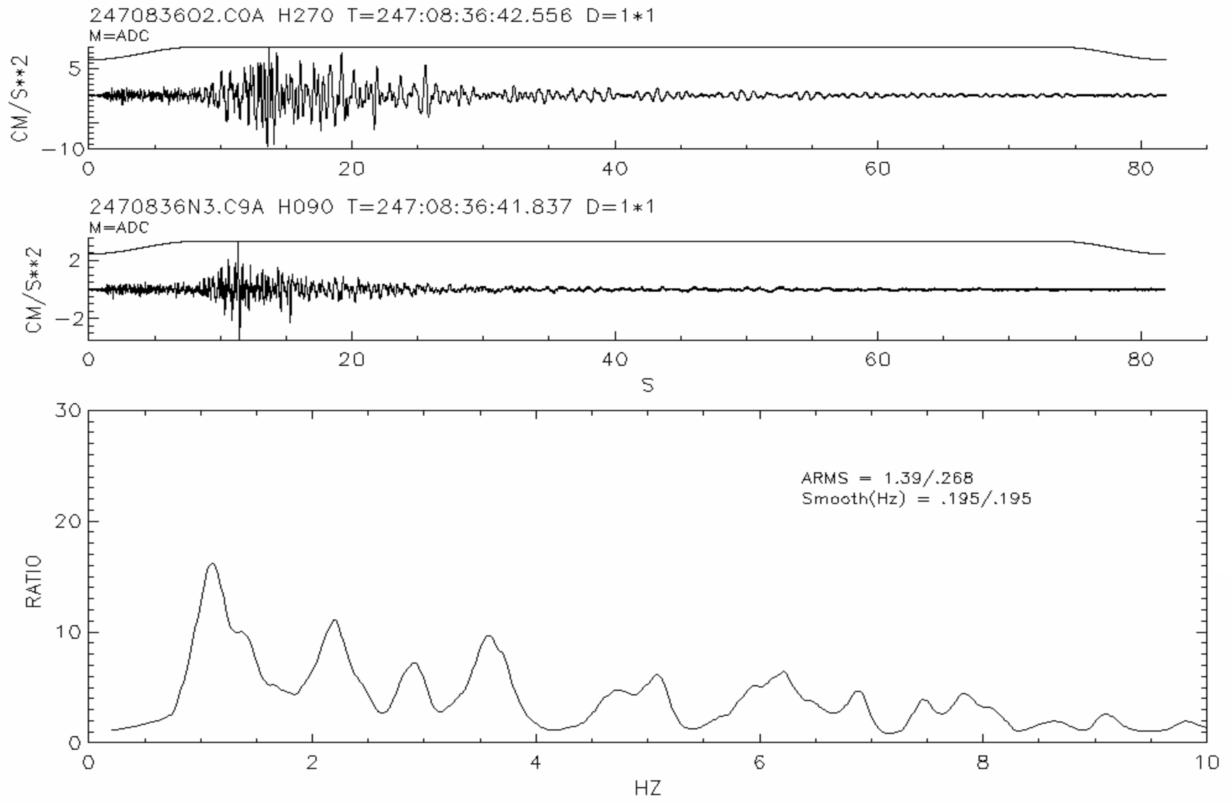
# Bessie Carmichael Spectral Ratio (Surface NS / 90 Meters NS)

## Yountville Earthquake, M=5.1



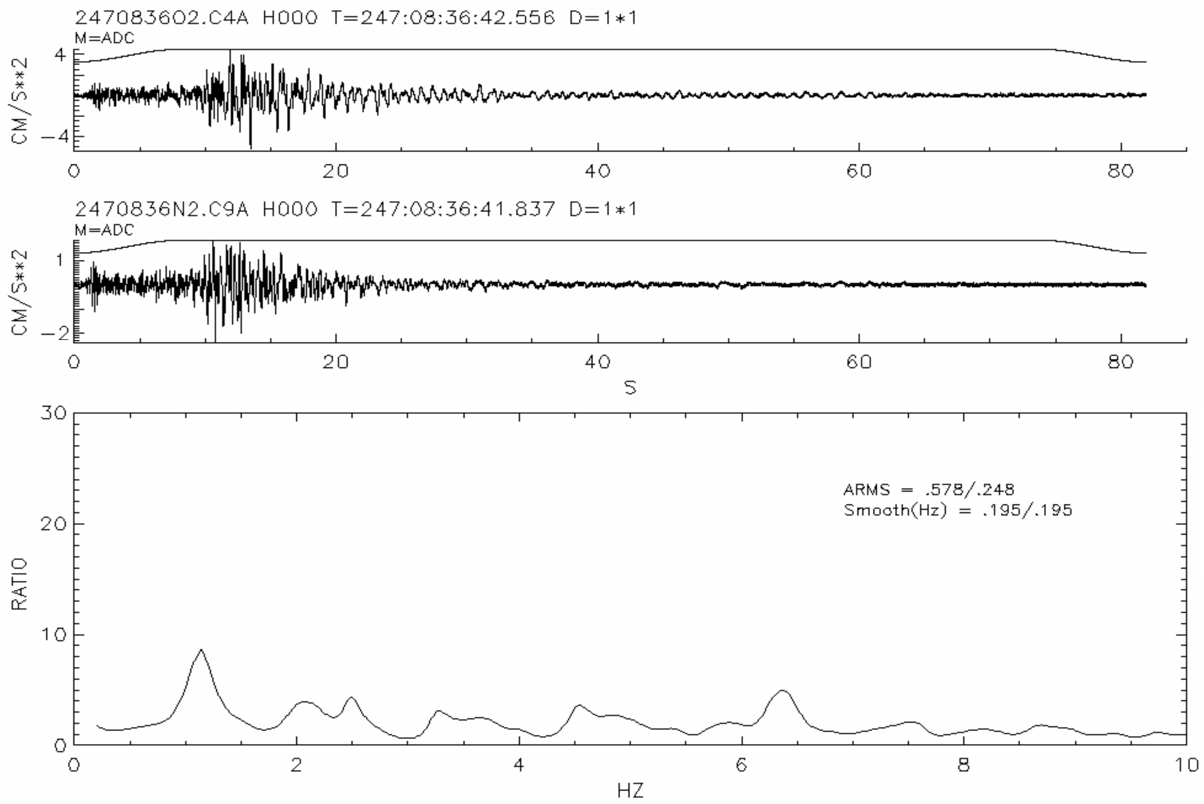
# Bessie Carmichael Spectral Ratio (Surface EW / 90 Meters EW)

## Yountville Earthquake, M=5.1



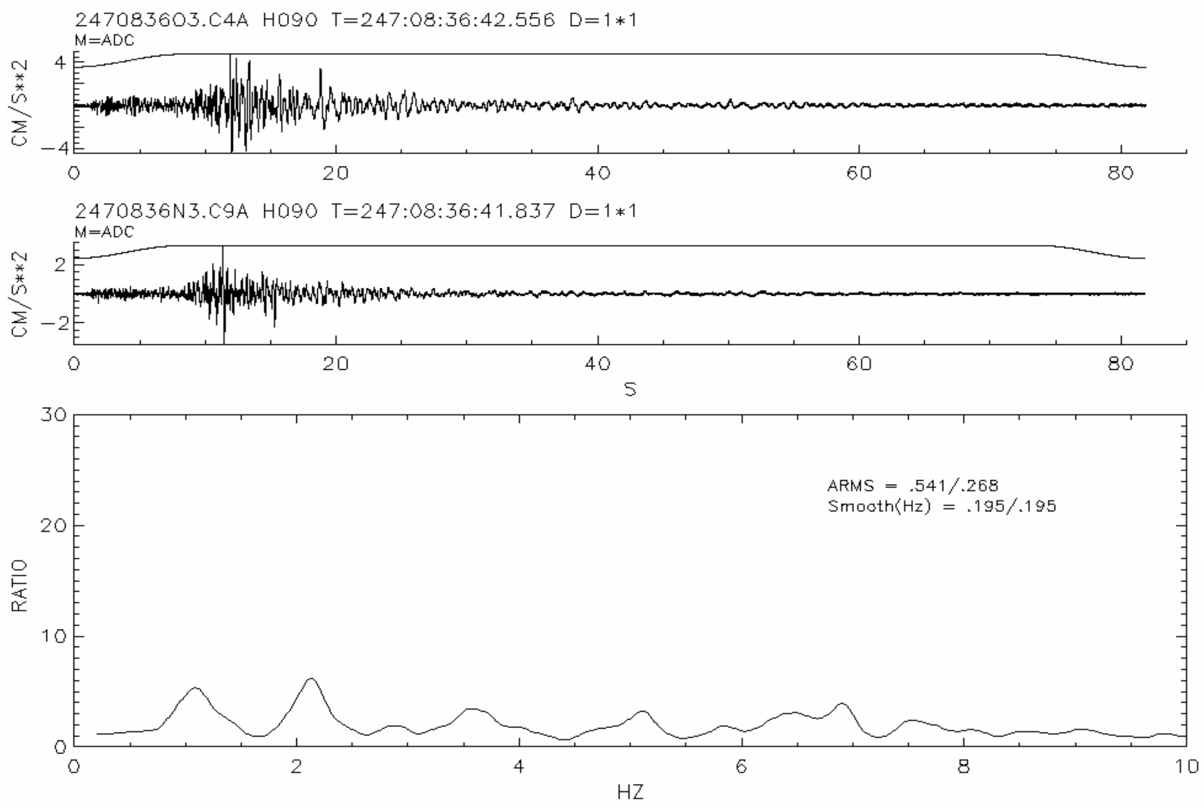
# Bessie Carmichael Spectral Ratio (37 Meters NS / 90 Meters NS)

**Yountville Earthquake, M=5.1**



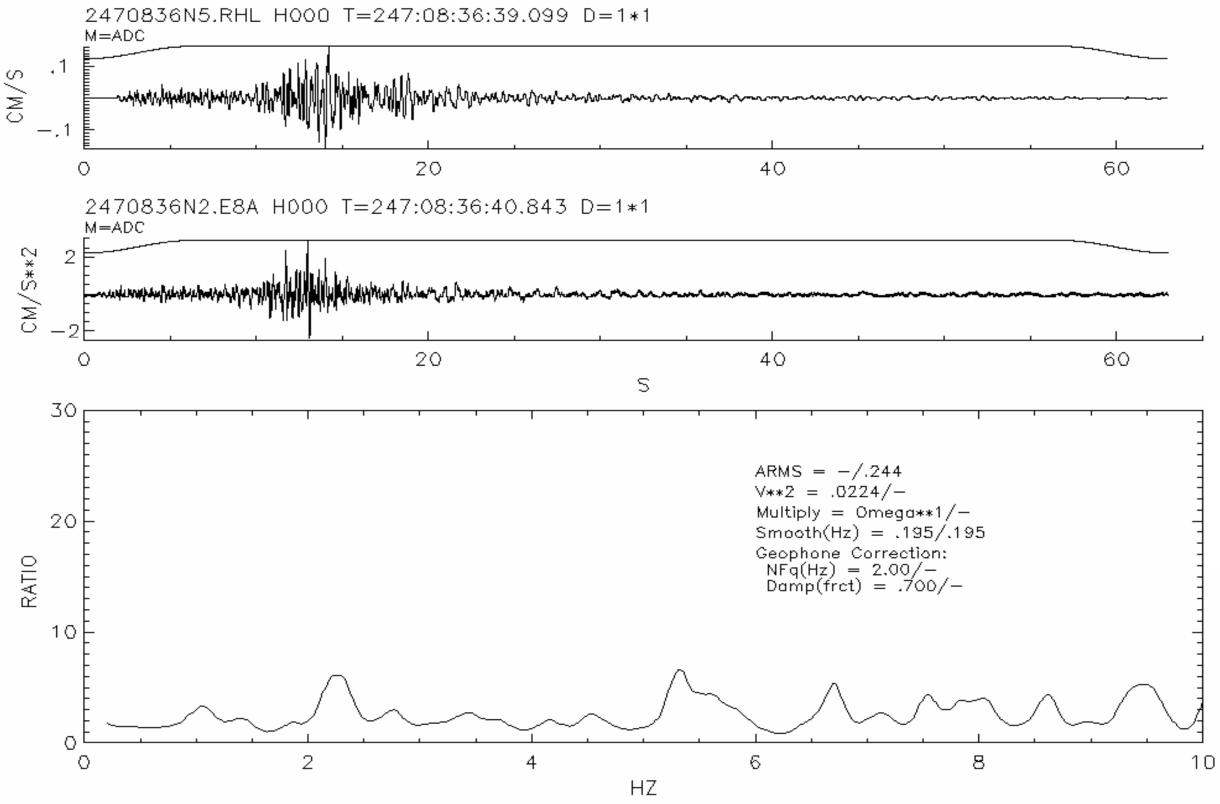
# Bessie Carmichael Spectral Ratio (37 Meters EW / 90 Meters EW)

**Yountville Earthquake, M=5.1**



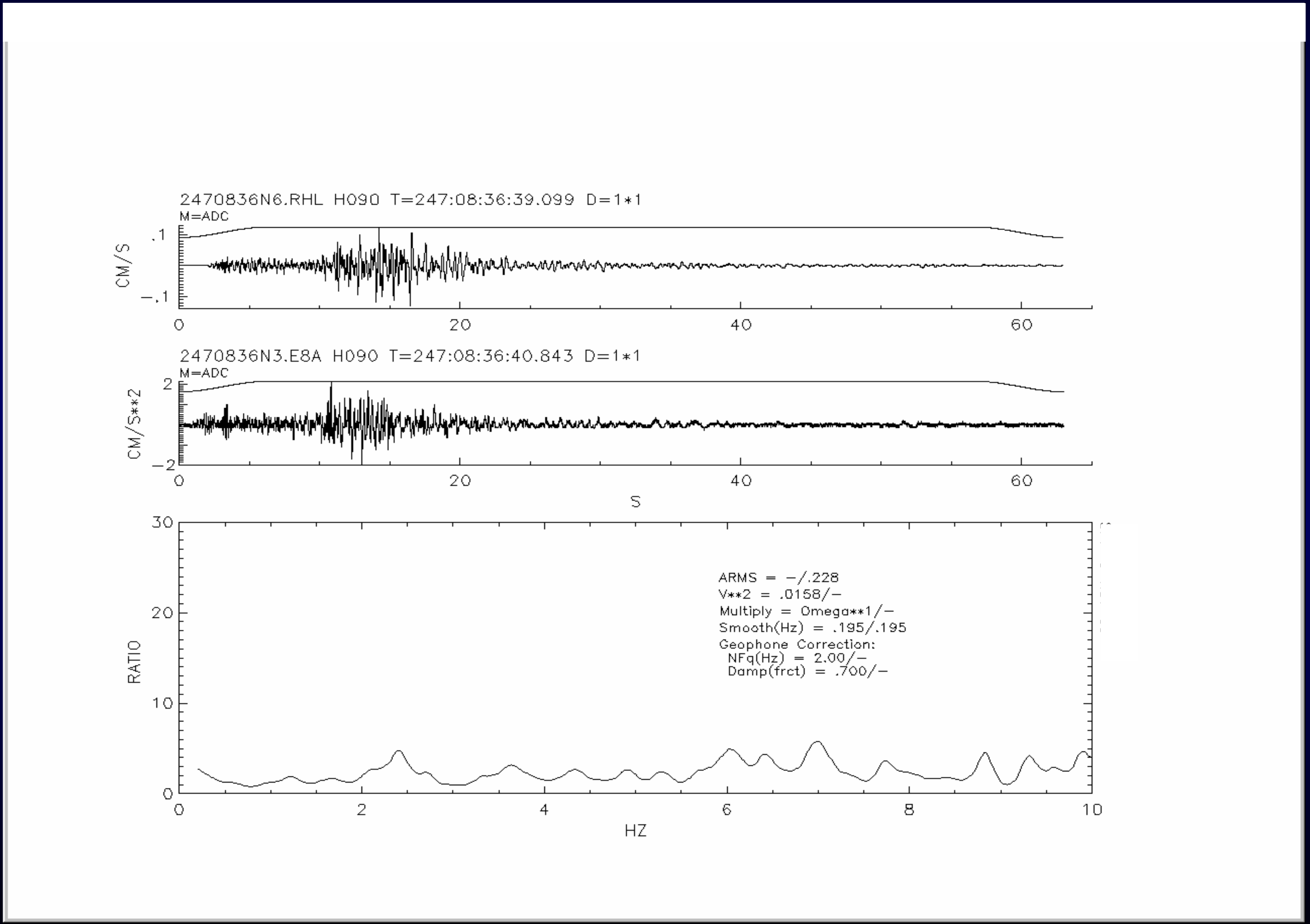
# Spectral Ratio (Russian Hill Surface NS / Embarcadero Plaza 79 Meters EW)

**Yountville Earthquake, M=5.1**

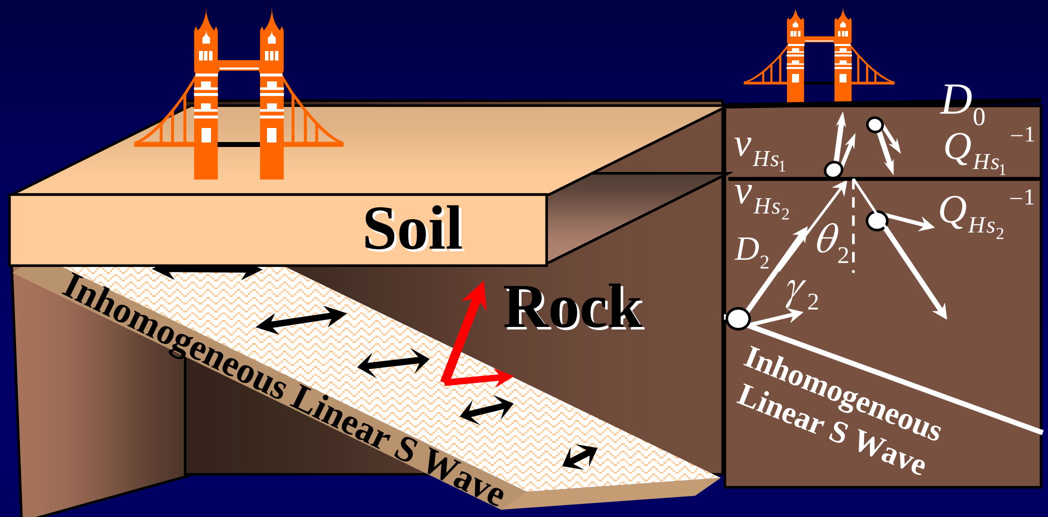


# Spectral Ratio (Russian Hill Surface EW / Embarcadero Plaza 79  Meters EW)

**Yountville Earthquake, M=5.1**

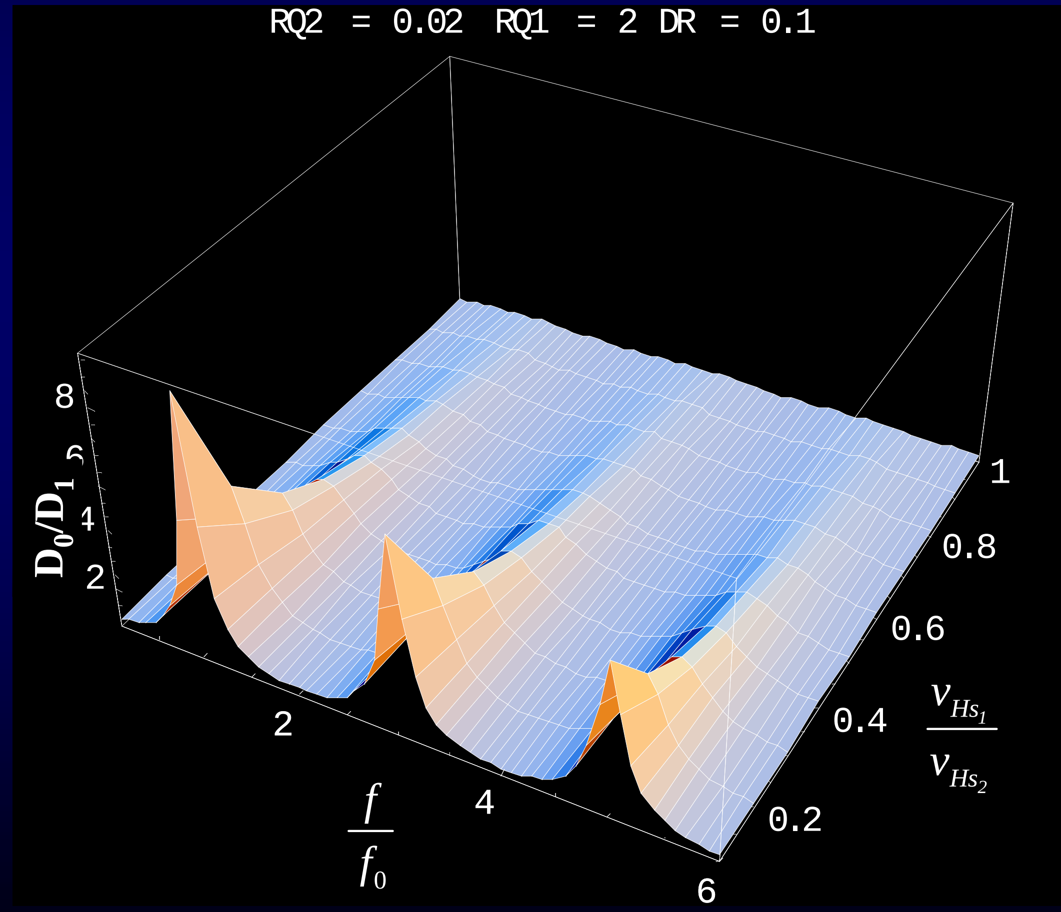


# Theoretical Response of a Viscoelastic Soil Layer as a Simple Model for Site Coefficients in Bldg. Codes




## Amplitude Response versus Frequency

### Homogeneous Linear S Wave, Vertical Incidence




## Solution:

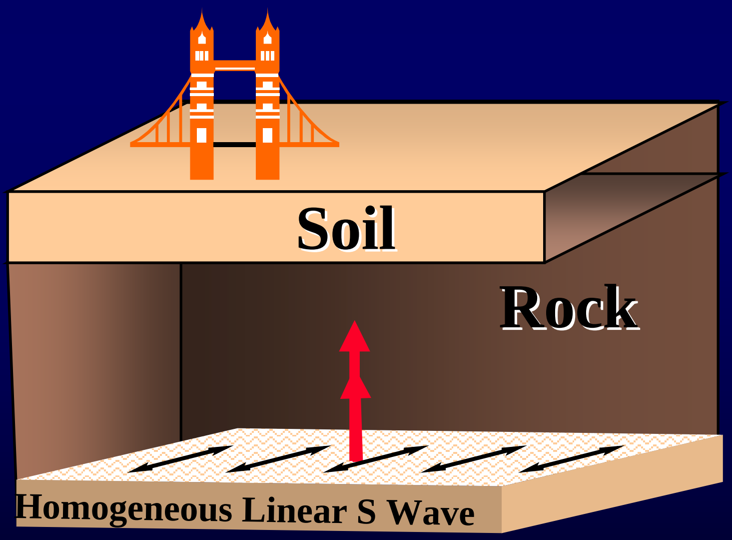
$$\frac{D_0}{D_1} = \mathrm{F}[(\textit{inc. wave field par.}),(\textit{material par.})]$$

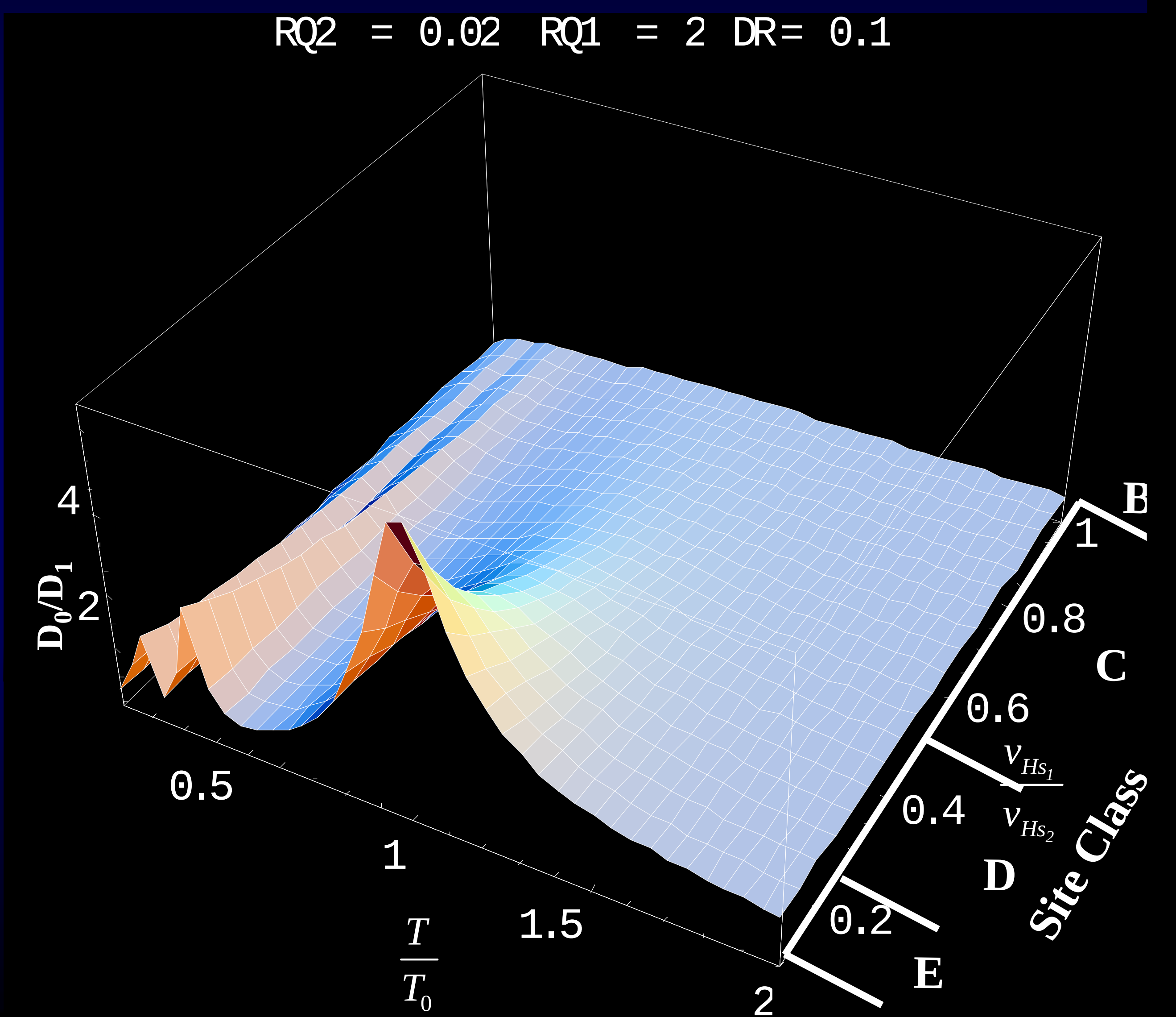
$$\frac{D_0}{D_1} = \mathrm{F}[(\theta_2, \gamma_2, \frac{f}{f_0}), (\frac{v_{Hs_1}}{v_{Hs_2}}, Q_{Hs_1}{}^{-1}, Q_{Hs_2}{}^{-1}, \frac{\rho_1}{\rho_2})]$$

where $f_0$=fundamental frequency.

# Amplitude Response versus Period, Shear Velocity, and Bldg. Code Site Class

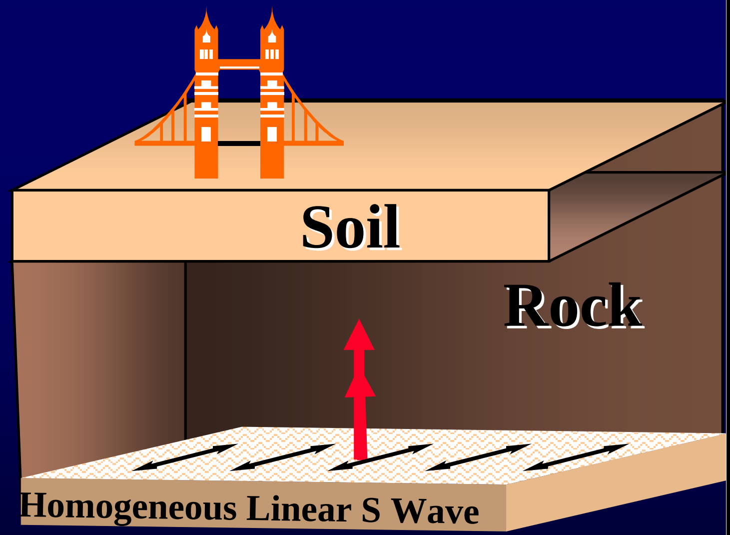
**Anelastic Soil Layer**
**Damping Ratio 5%**
**Vertical Incidence**

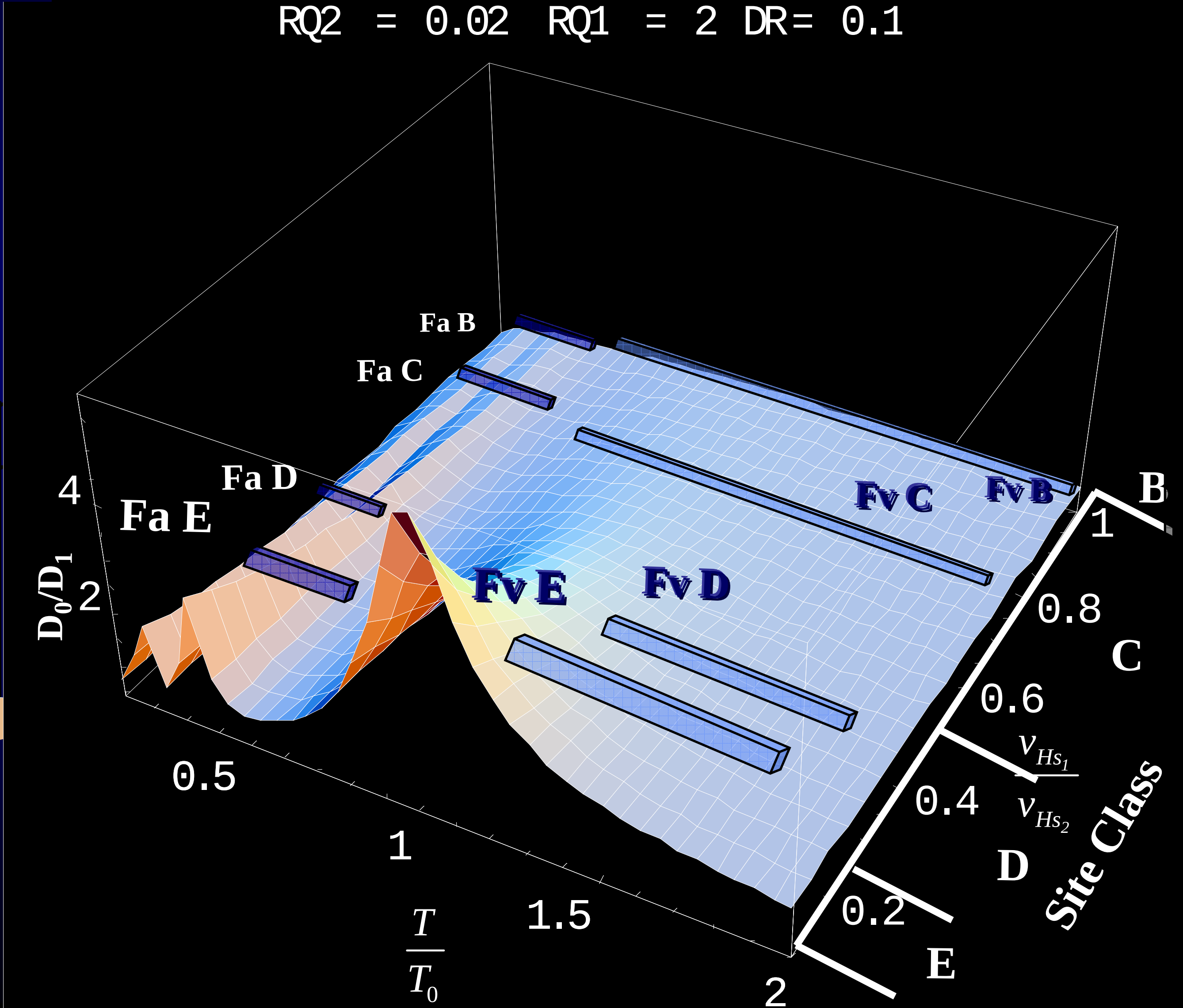


# Bldg. Code Site Coefficients
# Theoretical Response at 5 % Damping or $I_a$~ 0.1g

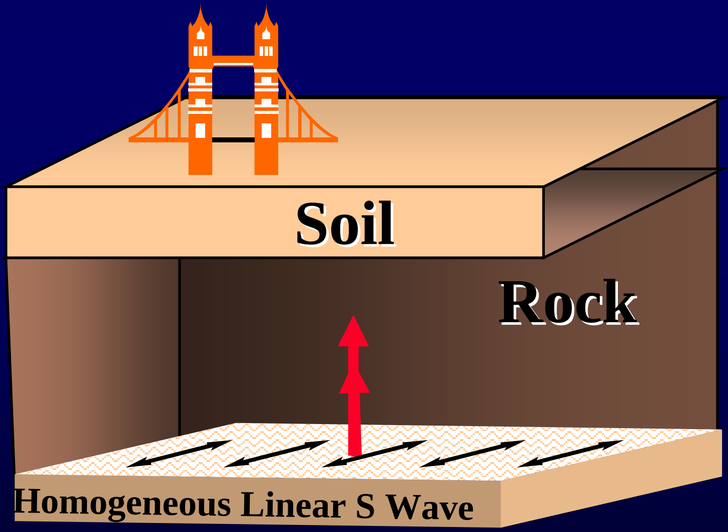
**Anelastic Soil Layer**
**Damping Ratio 5%**
**Ia ~ 0.1g**
**Vertical Incidence**

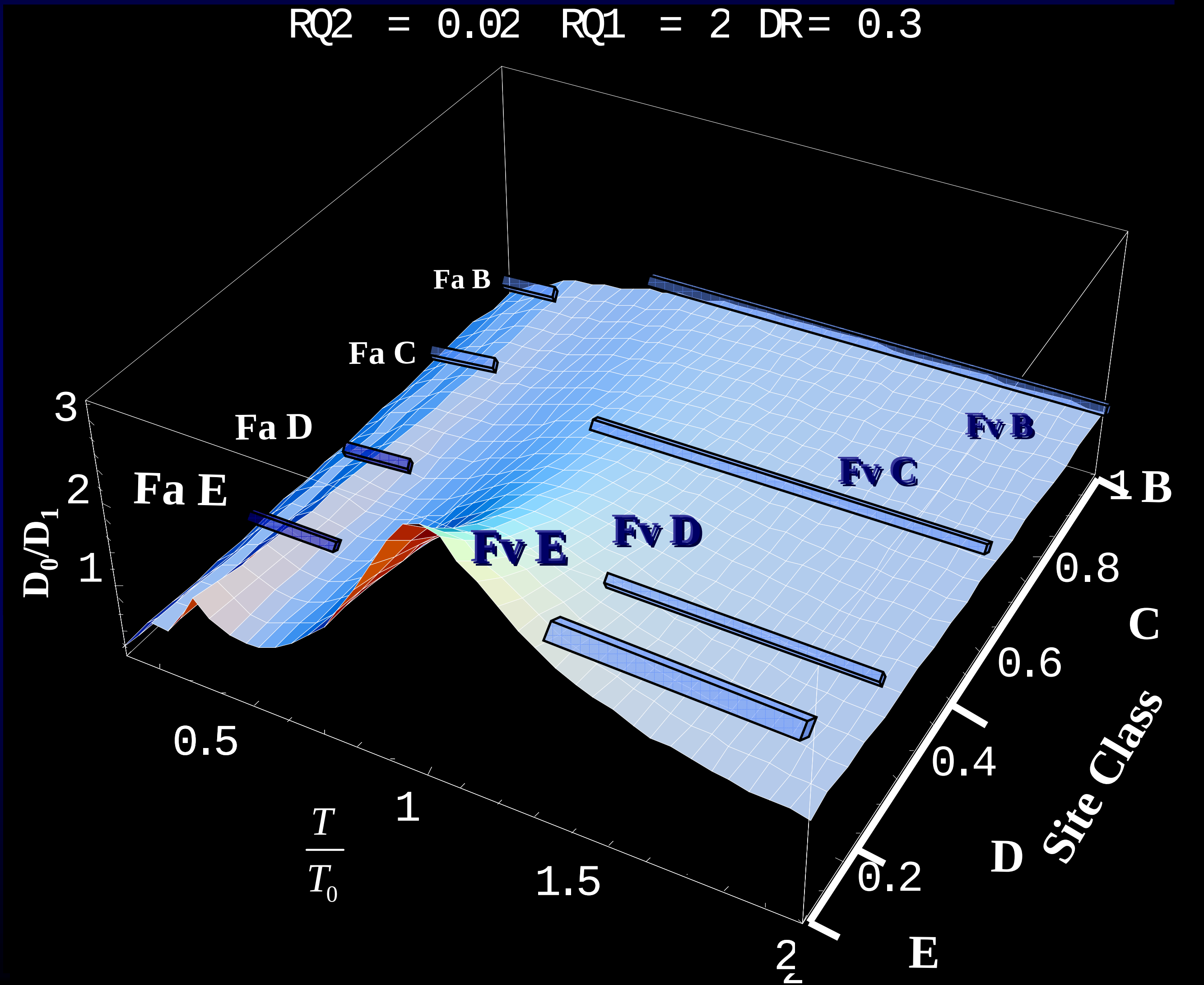


# Bldg. Code Site Coefficients and Theoretical Response
# 15 % Damping or $I_a$~ 0.4 g

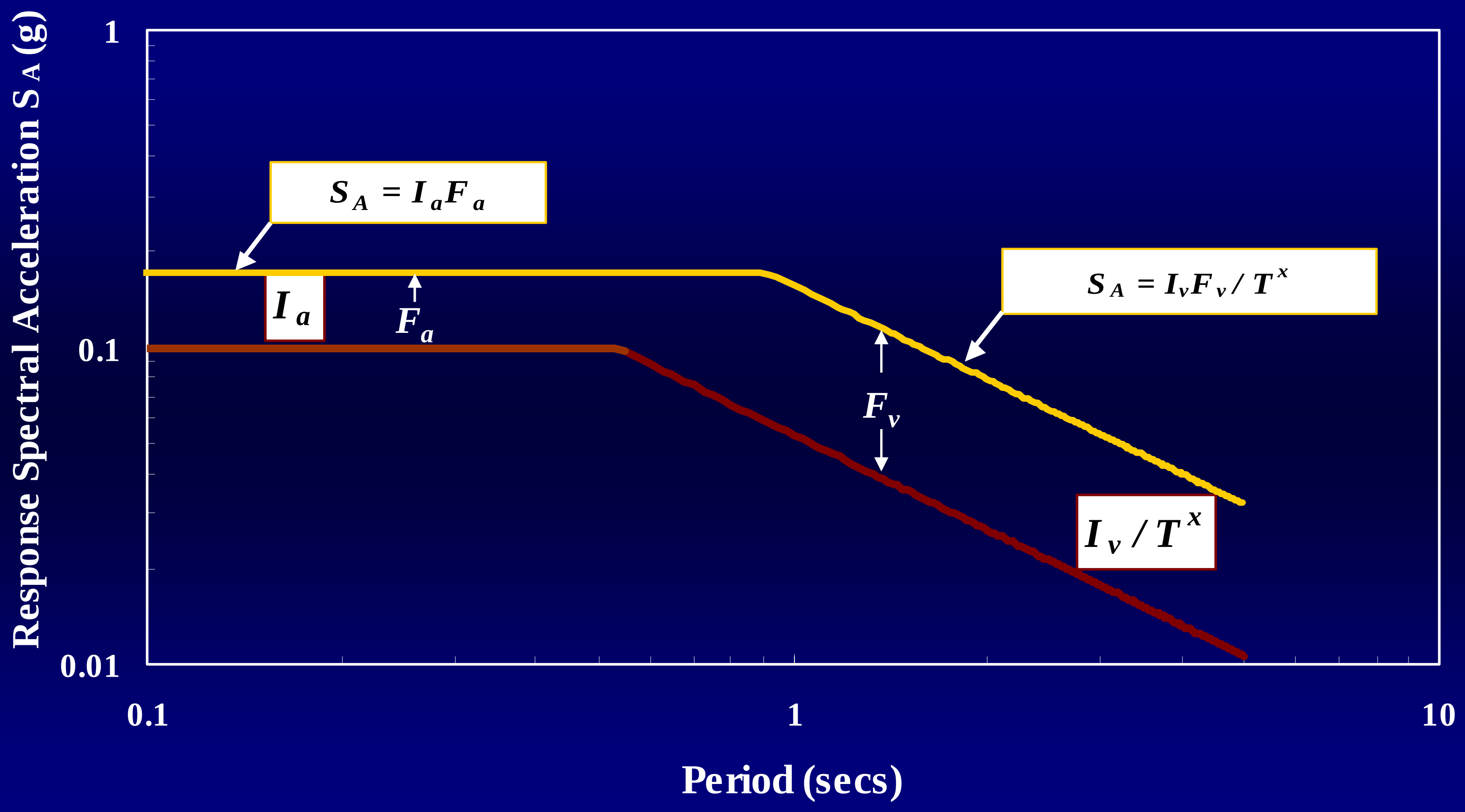
Anelastic Soil Layer
Damping Ratio 15 %
Ia ~0.4 g
Vertical Incidence



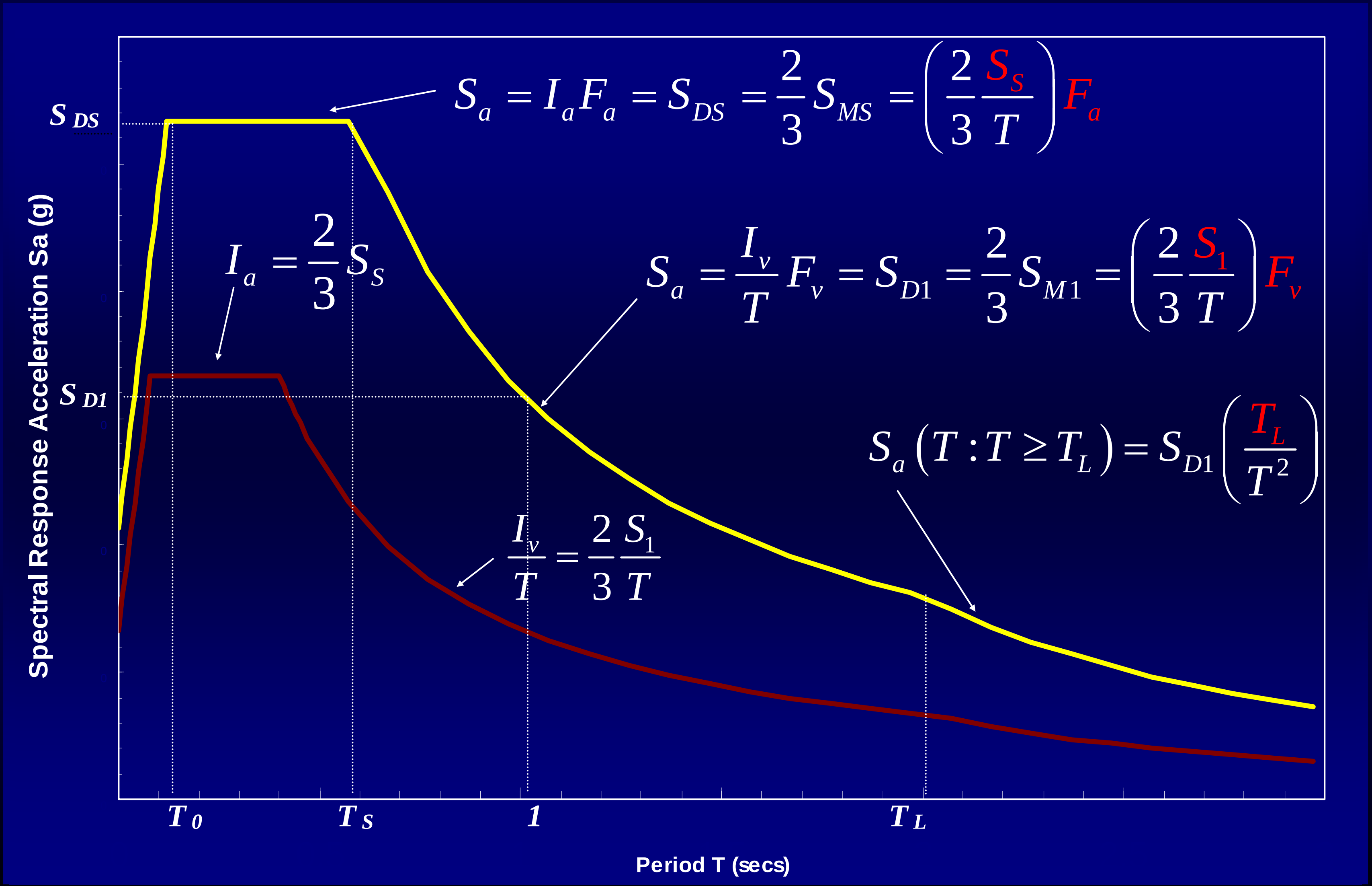
# Definition of Site-Dependent Response Spectra (log-log scale)

**(NEHRP, UBC, IBC, ASCE 7 Provisions)**



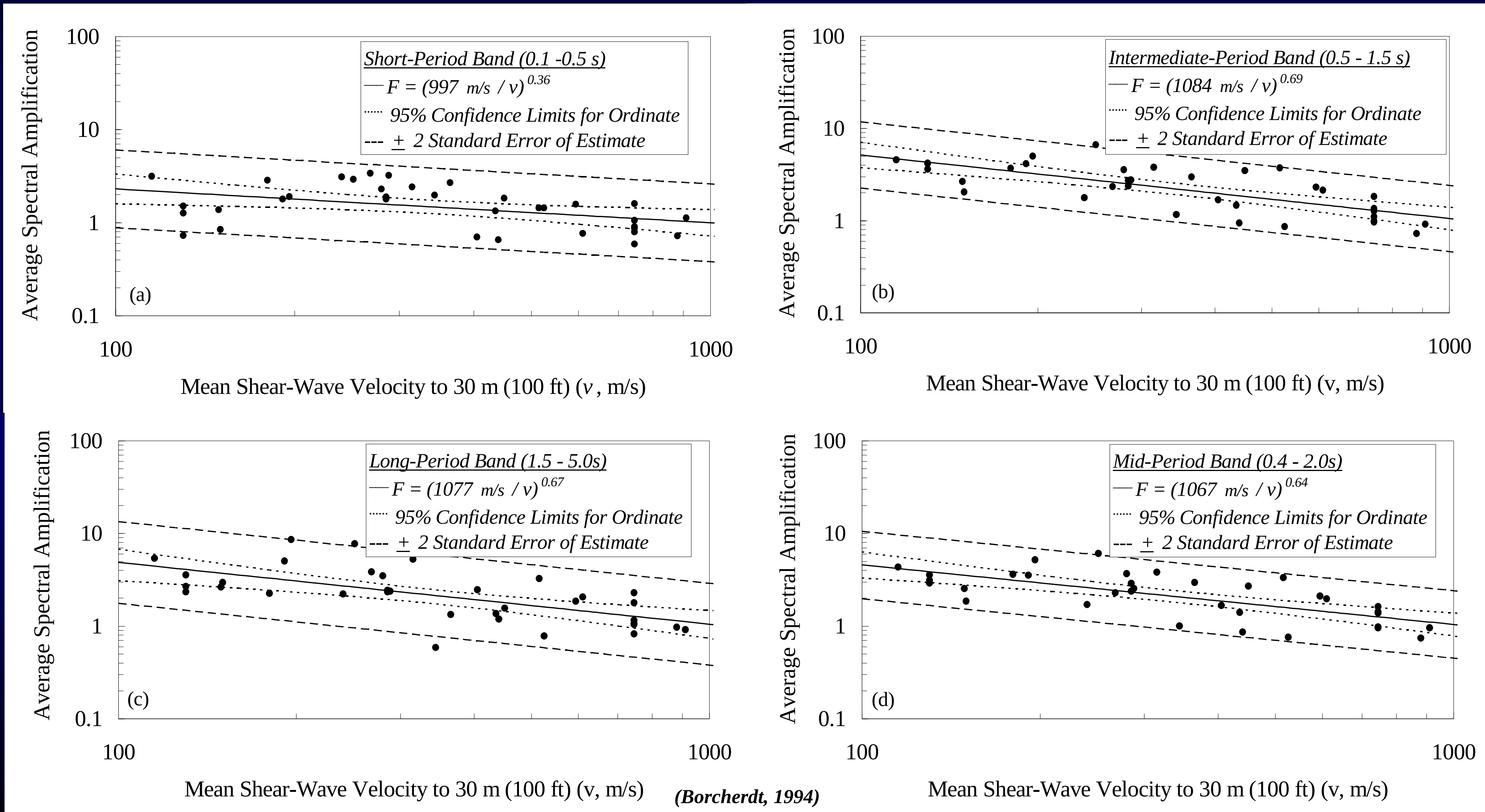
# Site-Dependent Response Spectra (linear-linear scale)

## (NEHRP, UBC, IBC, ASCE 7 Provisions)



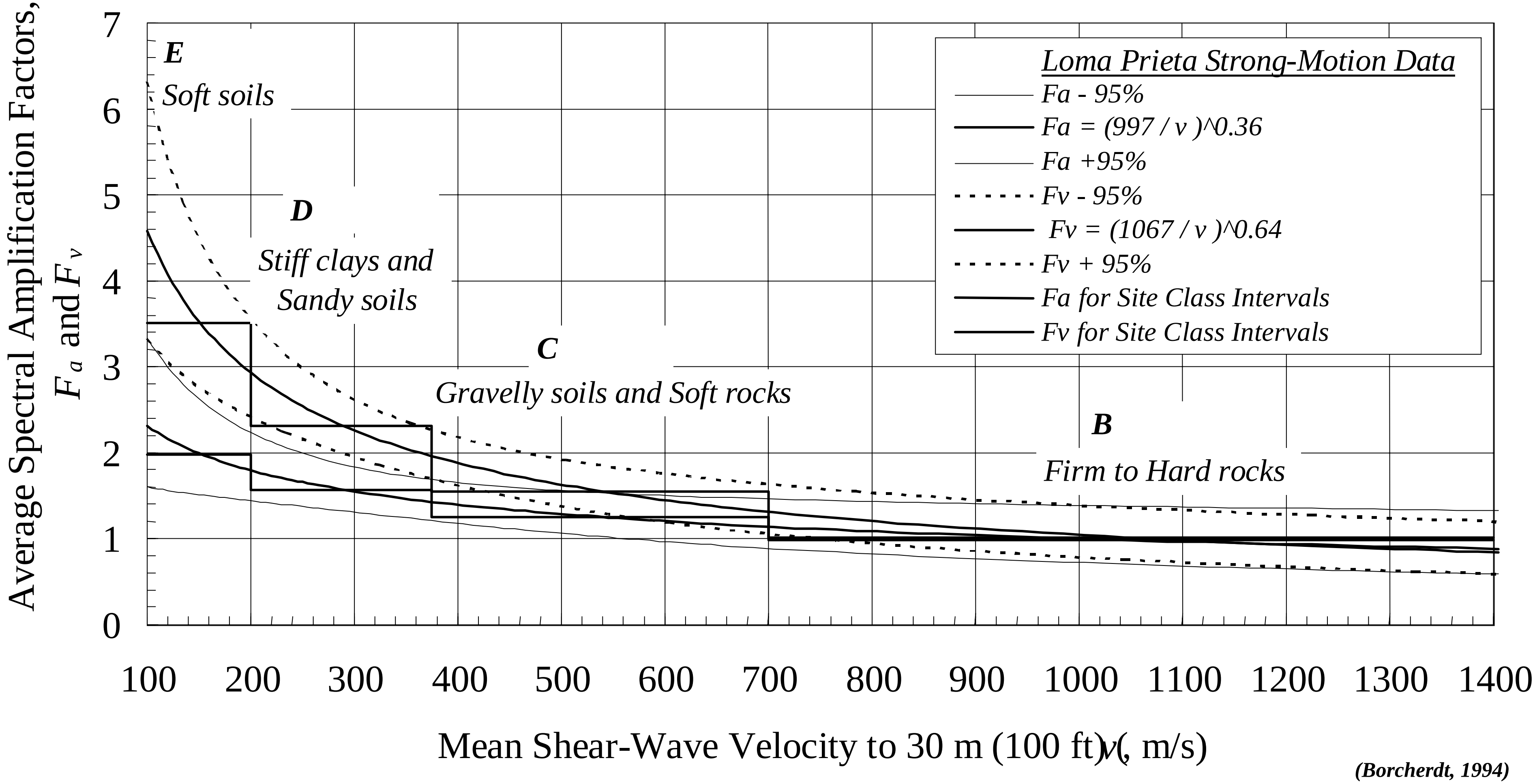
# Spectral Amplification Dependence on Shear Wave Velocity (*Vs*)

## Loma Prieta Earthquake; $I_a \leq 0.1g$



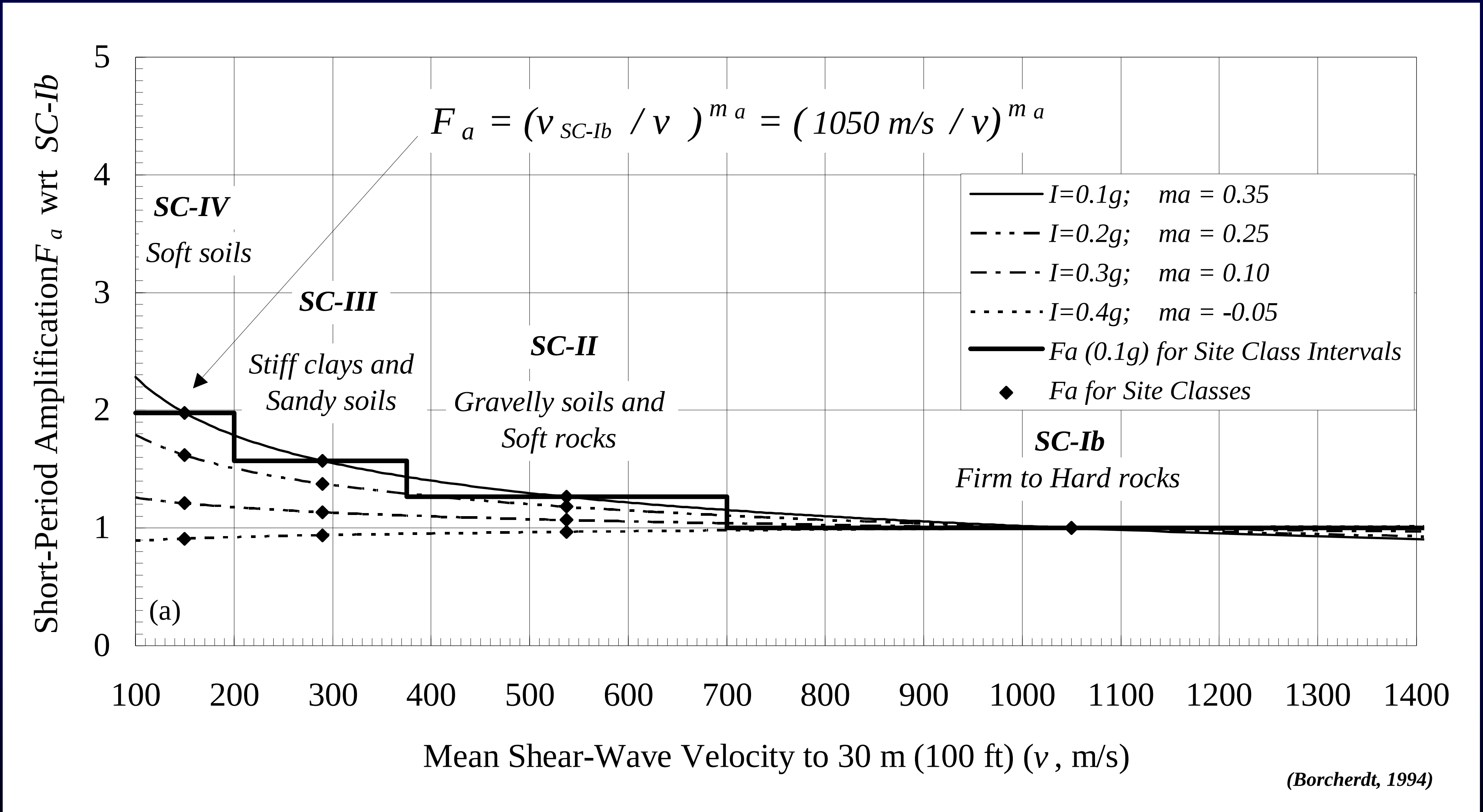
# Short and Mid-Period Site Coefficients versus Vs30

# $F_a$ and $F_v$ for $I_a \leq 0.1g$



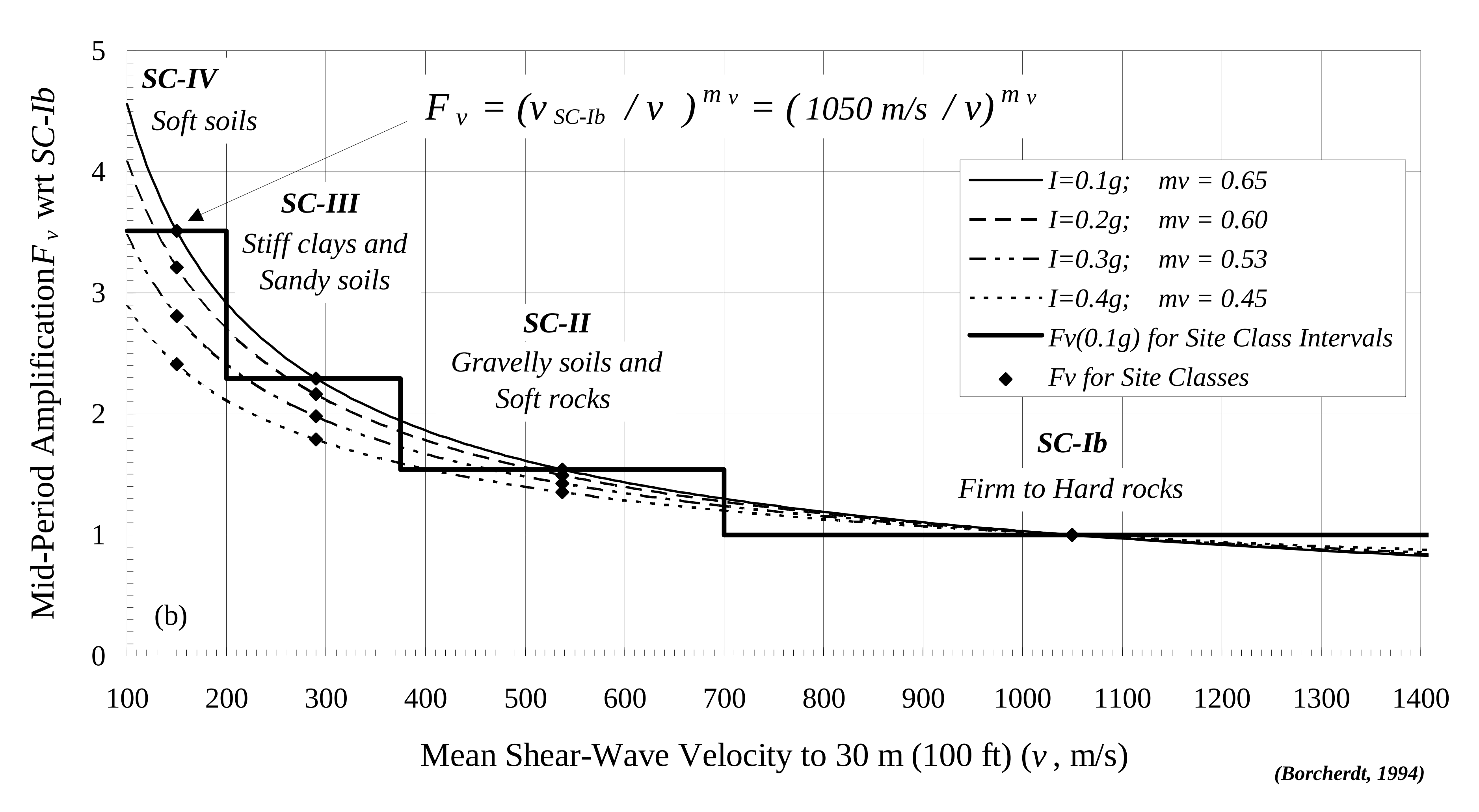
# $F_a$ versus Vs30 and Input Acceleration

## $I_a$ = 0.1, 0.2, 0.3, 0.4 g *(linear scales)*



# $F_v$ versus Vs30 and Input Acceleration

## $I_v$ = 0.1, 0.2, 0.3, 0.4 g *(linear scales)*



# Short-Period Site Coefficient $F_a$

## (NEHRP, UBC, IBC, ASCE-7 Provisions)

| Site Class | $A_a \leq 0.1$ | $A_a = 0.20$ | $A_a = 0.30$ | $A_a = 0.40$ | $A_a \geq 0.50$ |
|---|---|---|---|---|---|
| | $S_s < 0.25$ | $S_s = 0.50$ | $S_s = 0.75$ | $S_s = 1.00$ | $S_s \geq 1.25$ |
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.2 | 1.2 | 1.1 | 1.0 | 1.0 |
| D | 1.6 | 1.4 | 1.2 | 1.1 | 1.0 |
| E | 2.5 | 1.7 | 1.2 | 0.9 | * |
| F | * | * | * | * | * |

* Site-specific geotechnical investigation and dynamic site response analysis shall be performed.

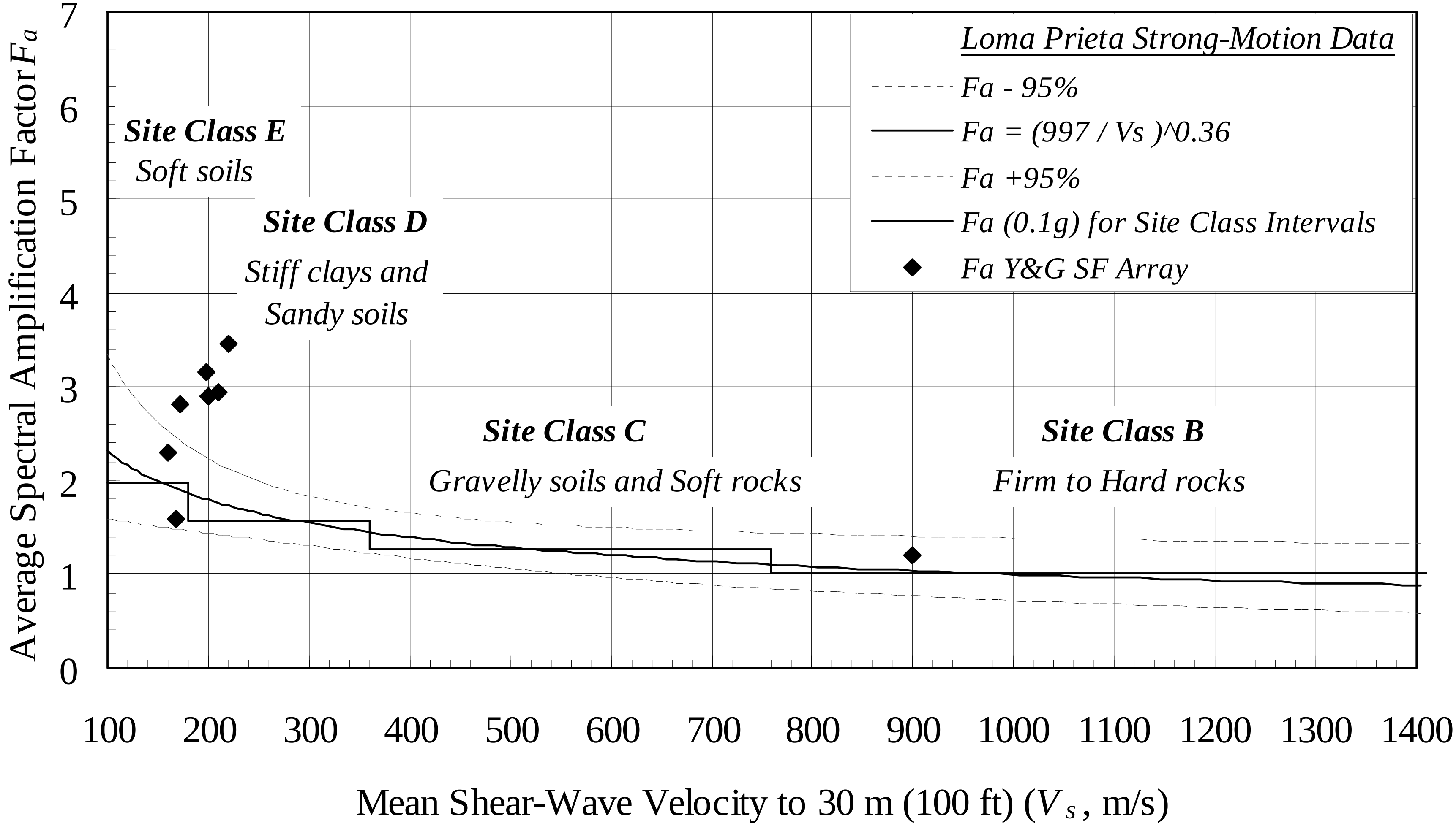
# Mid-Period Site Coefficient $F_v$

## (NEHRP, UBC, IBC, ASCE-7 Provisions)

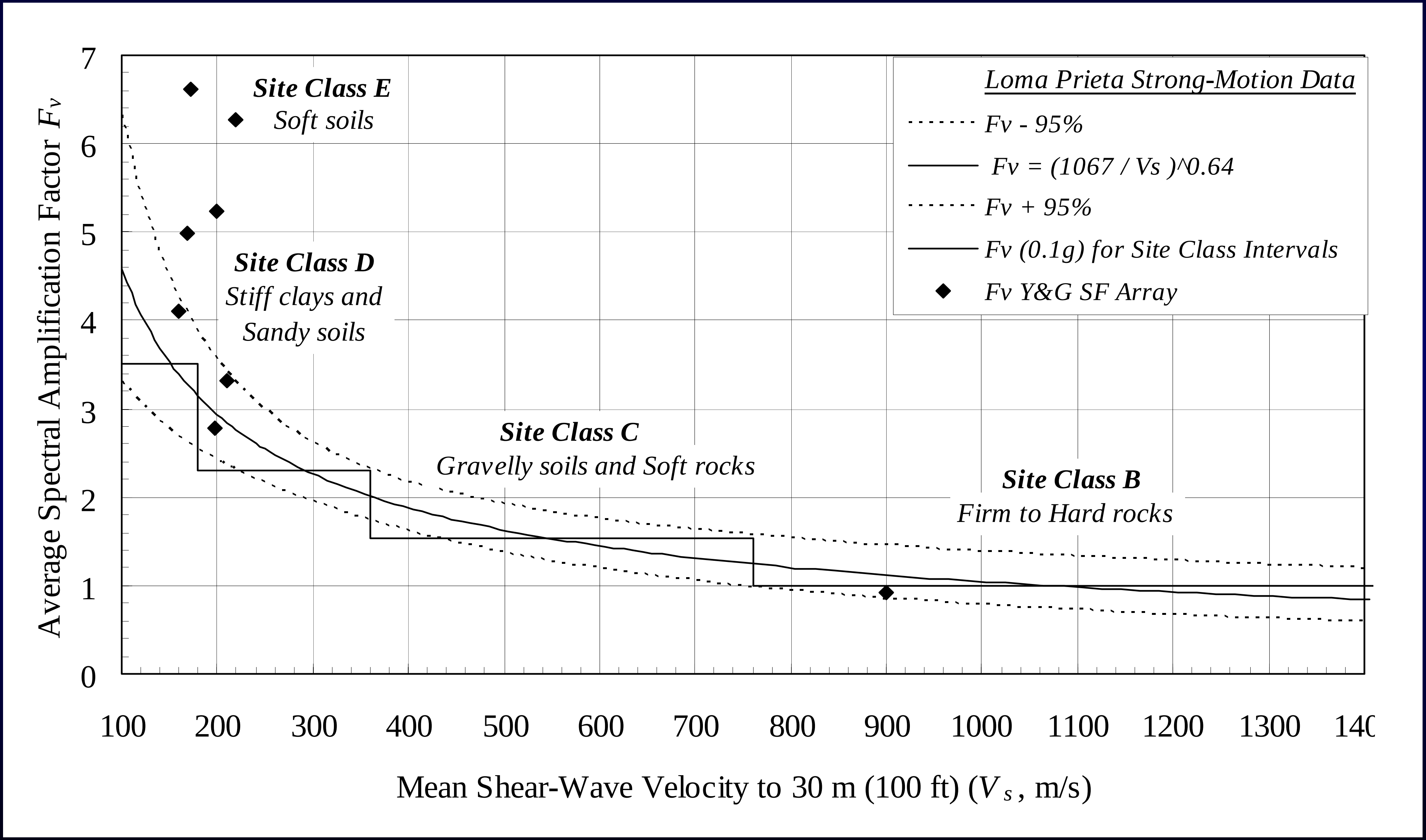
| Site Class | $A_v \leq 0.1$ $S_l < 0.1$ | $A_v = 0.20$ $S_l = 0.20$ | $A_v = 0.30$ $S_l = 0.30$ | $A_v = 0.40$ $S_l = 0.40$ | $A_v \geq 0.50$ $S_l \geq 0.50$ |
|---|---|---|---|---|---|
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 |
| D | 2.4 | 2.0 | 1.8 | 1.6 | 1.5 |
| E | 3.5 | 3.2 | 2.8 | 2.4 | * |
| F | * | * | * | * | * |

* Site-specific geotechnical investigation and dynamic site response analysis shall be performed.

# Empirical Measurements of $F_a$ at SF Array Sites
## $F_a$ versus Vs30 Inferred from Loma Prieta Sites



# Empirical Measurements of $F_v$ at SF Array Sites
## $F_v$ versus Vs30 Inferred from Loma Prieta Sites



# Conclusions

- **Integrated Surface and Borehole SF Arrays provide unprecedented opportunity to measure in-situ high-strain constitutive properties of soft soils in SF region.**
- **Low-strain measurements to date on the array show large period-dependent amplification characteristics at sites underlain by thick layers of soft soil.**
- **Low-strain site response characteristics observed on SF arrays are consistent with those observed from previous low-strain comparative ground response measurements (Borcherdt et al., 1970, 1975, 1994).**
- **Bldg. code site coefficients, Fa and Fv, measured at some *Thick*, *Soft-soil* SF array sites are significantly greater, statistically, than those adopted in current code provisions.**
- **New site-specific procedure adopted for 2003 NEHRP provisions (Proposal 3-6 R; http://www.bssconline.org/2003NEHRPproposals.html) is recommended for purposes of seismic design and retrofit at *Thick*, *Soft-soil*, site-class E and D sites.**
- ***Thick*, *Soft-soil*, site-class E and D sites suggested for special-study considerations are those underlain by soils with Vs30 < 225 m/s, and interval Vs < 275 m/s to depths > 30 m.**