

Figure 1. Effects of near surface soil conditions on 5% damped response spectral shapes (source: Seed, Ugas, and Lysmor, 1976).

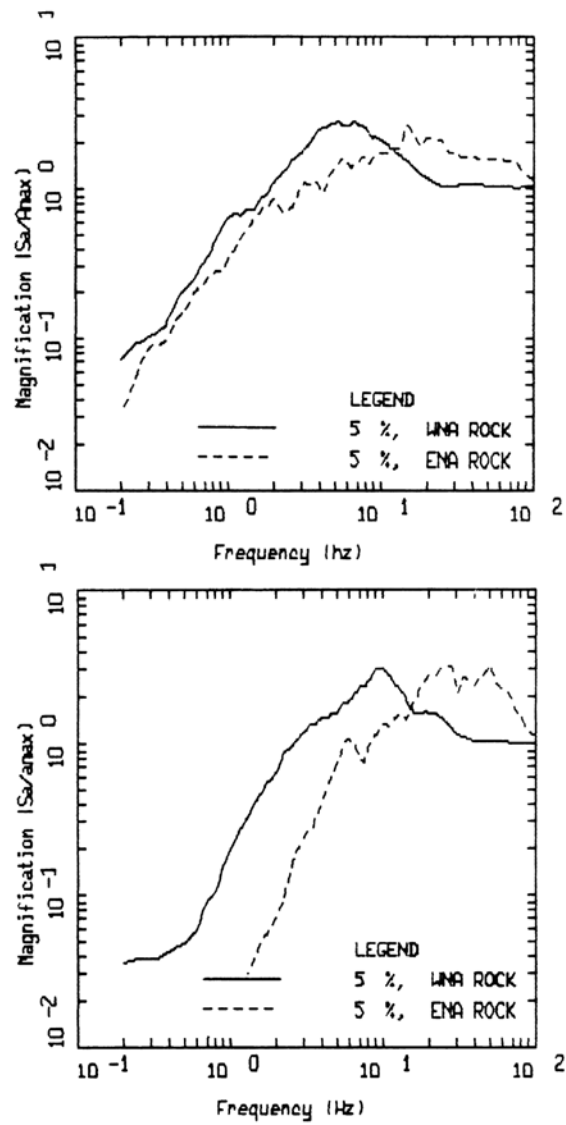


Figure 2. Effects of hard and soft rock site conditions and magnitude on 5% damped response spectral shapes for earthquakes with  $M \approx 6.5$  (upper) and  $M \approx 4.5$  (lower) (source: Silva and Darragh, 1995).

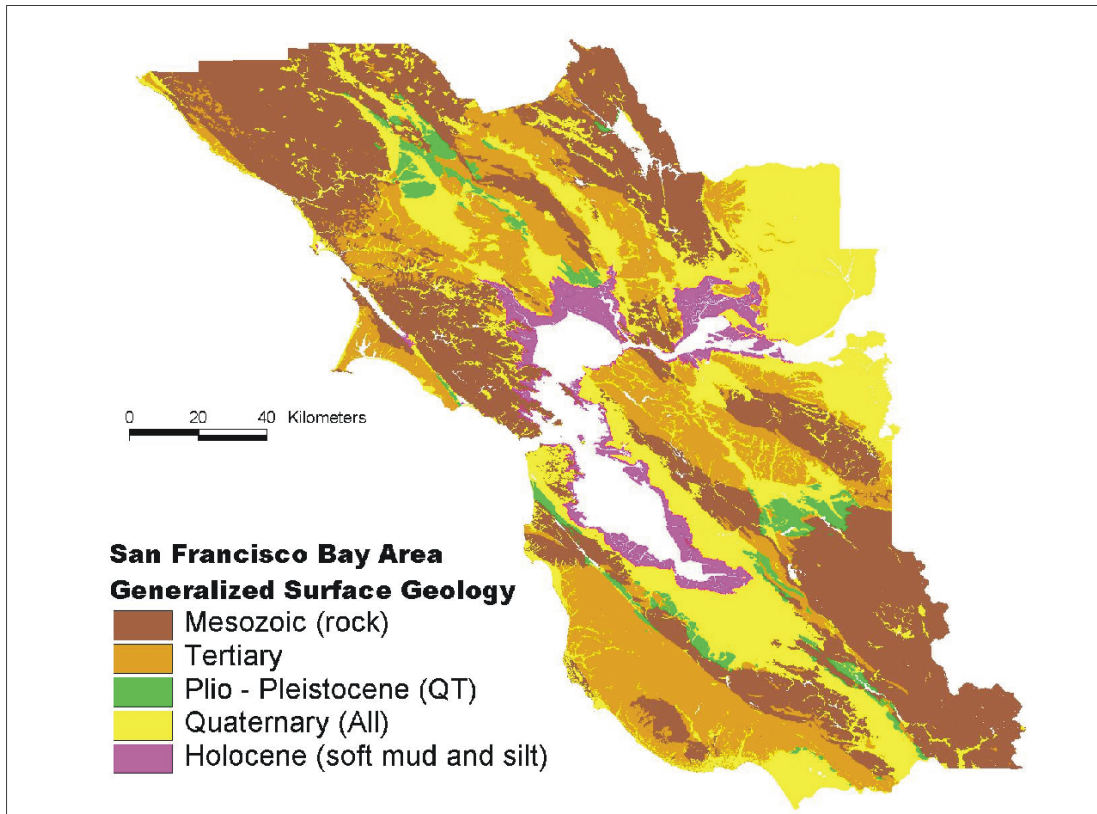
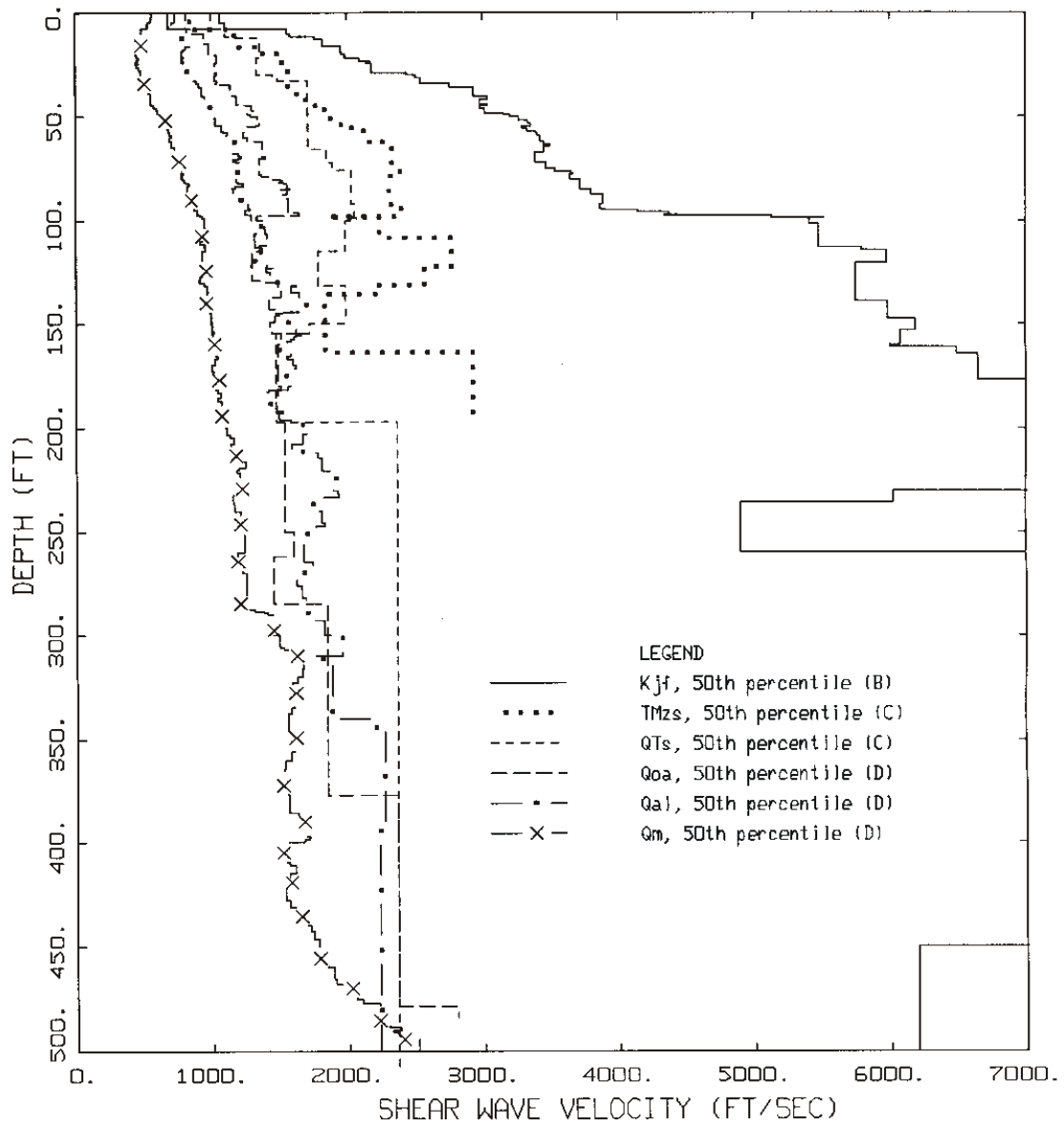
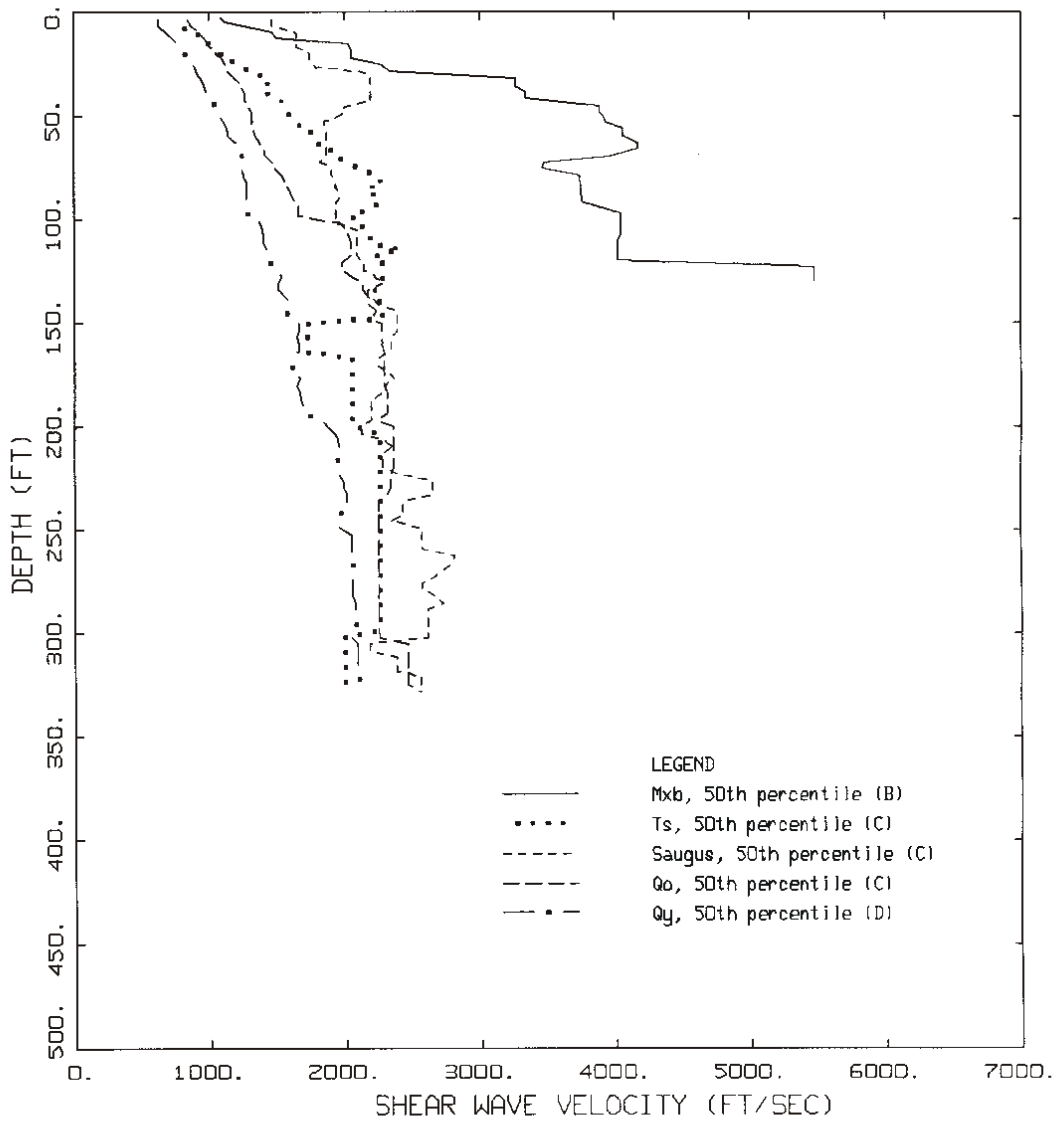


Figure 3. Mapped surface geology for the San Francisco Bay Area showing categories Bay Mud ( $Q_m$ ) Quaternary Alluvium ( $Q_{al} + Q_{oa}$ ), Quaternary/Tertiary ( $Q_{ts}$ ), Tertiary Bedrock ( $T_s$ ), and Franciscan ( $K_p$ ) (source: Wentworth (1997)).



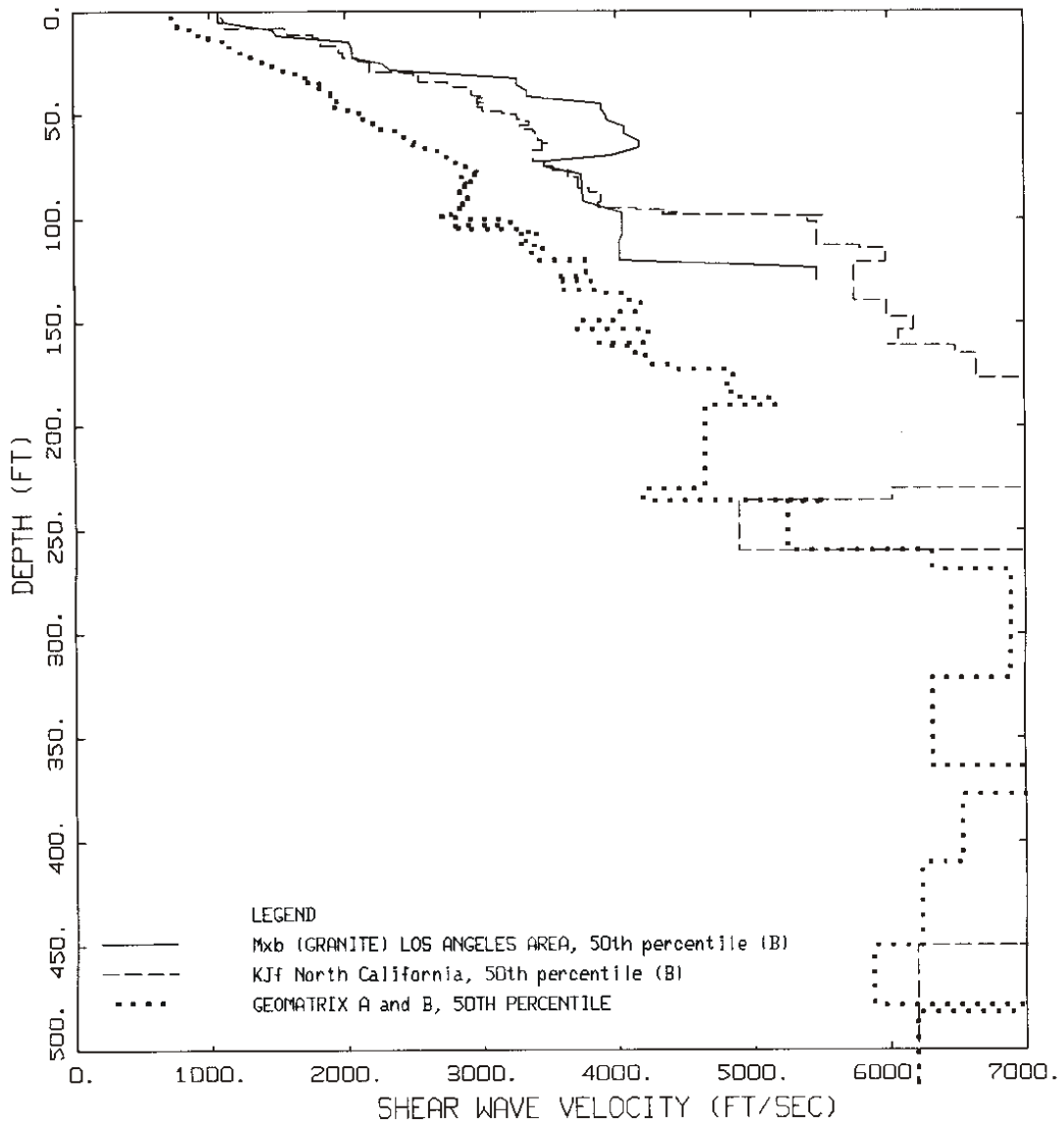
### SHEAR WAVE VELOCITY PROFILES SAN FRANCISCO

Figure 4. Surface geology based shear-wave velocity profiles for the San Francisco Bay area. Profiles are median estimates based on borehole measurements. Corresponding NEHRP categories are shown (Table 1).



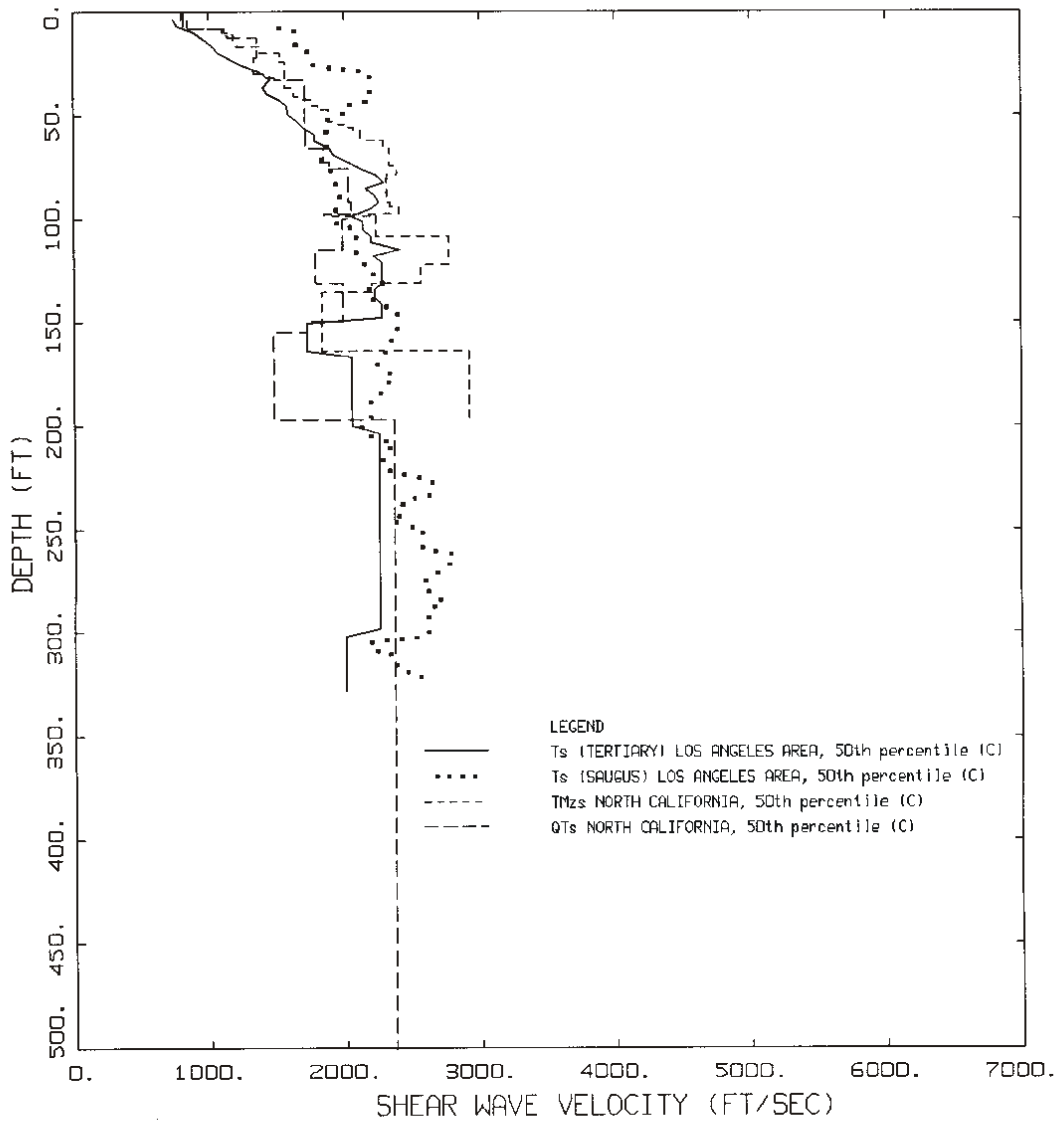
## SHEAR WAVE VELOCITY PROFILES LOS ANGELES

Figure 5. Surface geology based shear-wave velocity profiles for the Los Angeles area. Profiles are median estimates based on borehole measurements. Corresponding NEHRP categories are shown (Table 1).



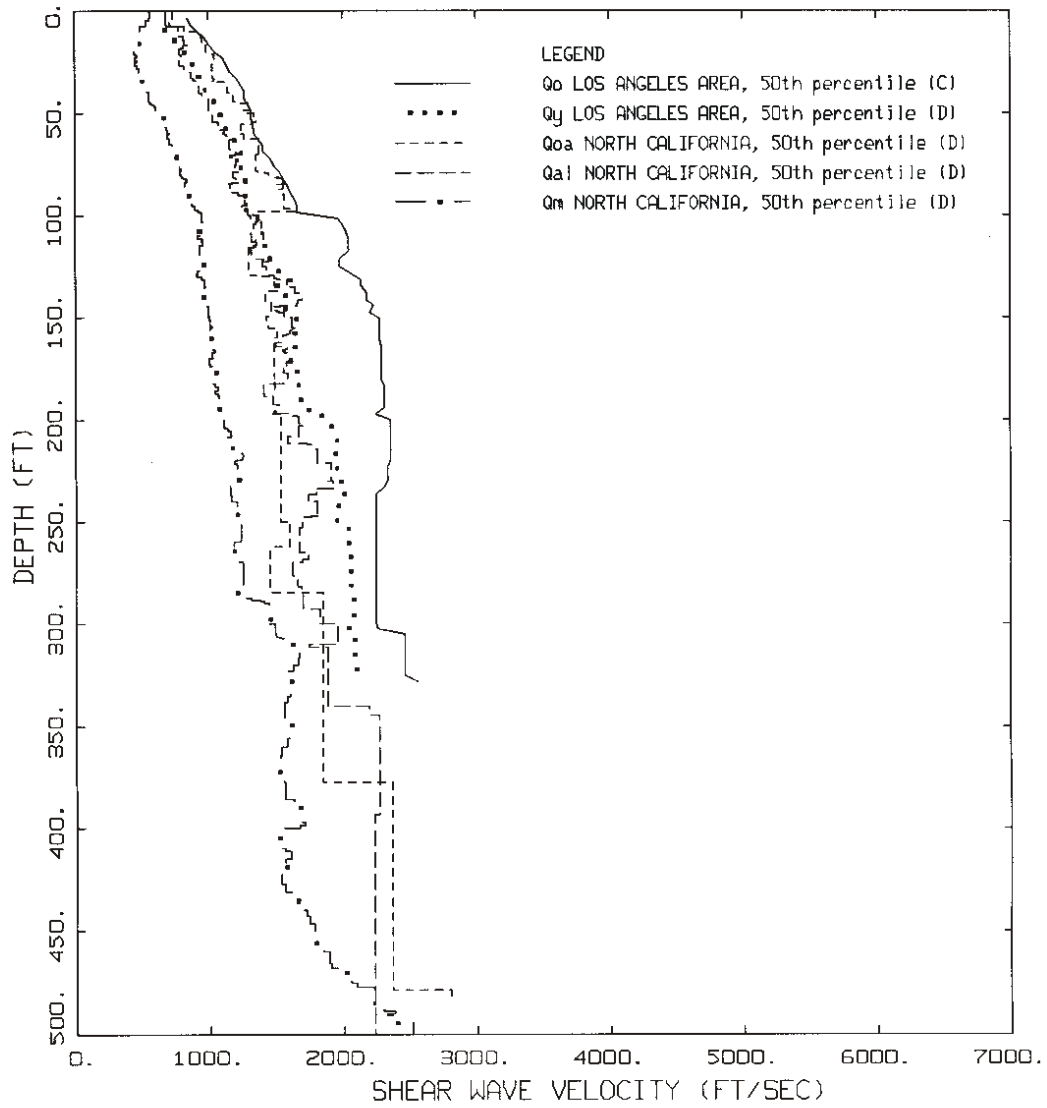
### SHEAR WAVE VELOCITY PROFILES SF, LA BASE ROCK COMPARISON

Figure 6. Comparison of median baserock shear-wave velocity profiles for San Francisco (Figure 4) and Los Angeles (Figure 5) areas. Dotted line is median profile for Geomatrix Category A and B, generally reflecting soft rock site conditions for California based empirical attenuation relations (Silva et al., 1997).



### SHEAR WAVE VELOCITY PROFILES SF, LA TERTIARY COMPARISON

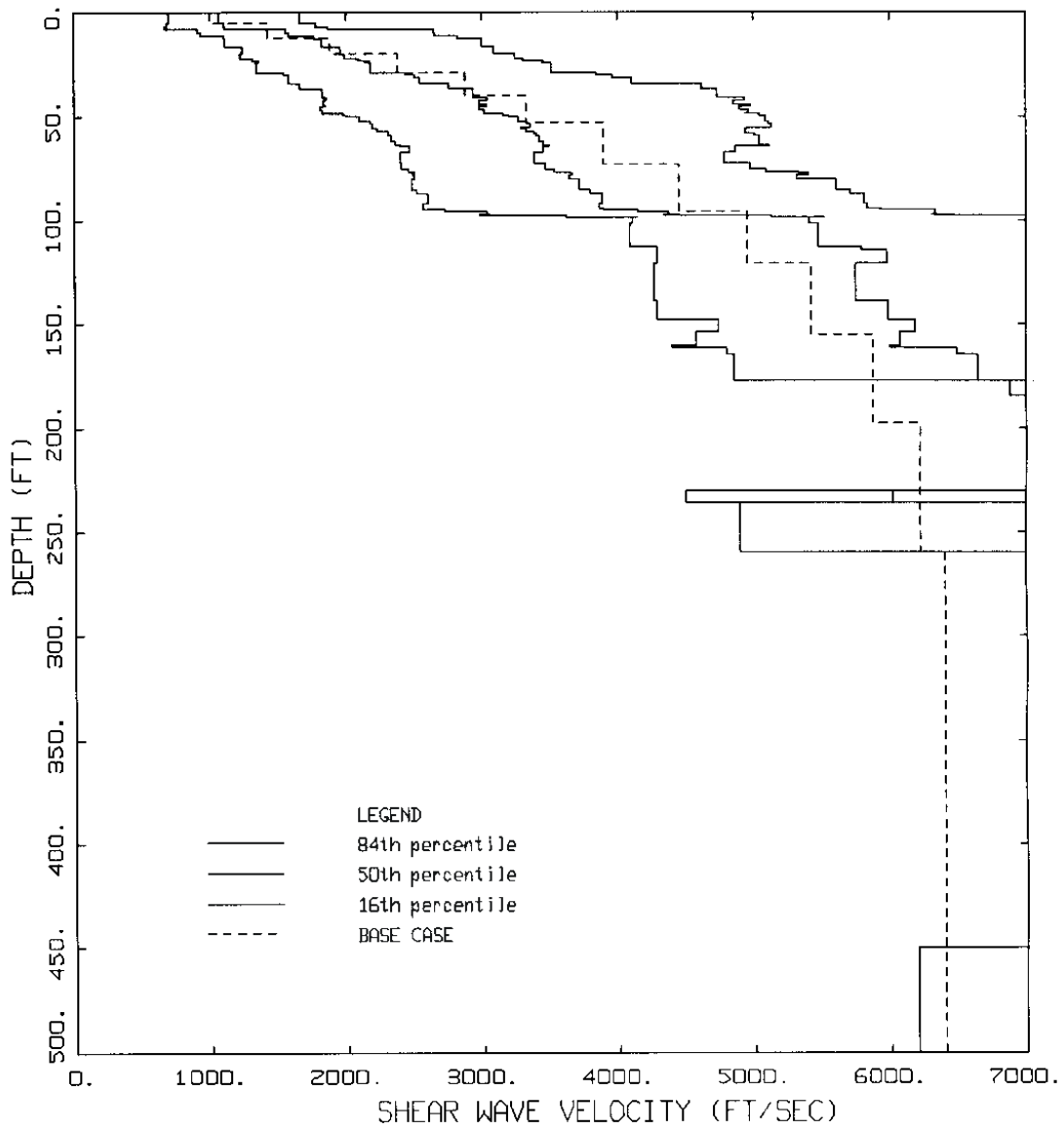
Figure 7. Comparison of median Tertiary shear-wave velocity profiles for San Francisco (Figure 4) and Los Angeles (Figure 5) areas.



### SHEAR WAVE VELOCITY PROFILES SF, LA ALLUVIUM COMPARISON

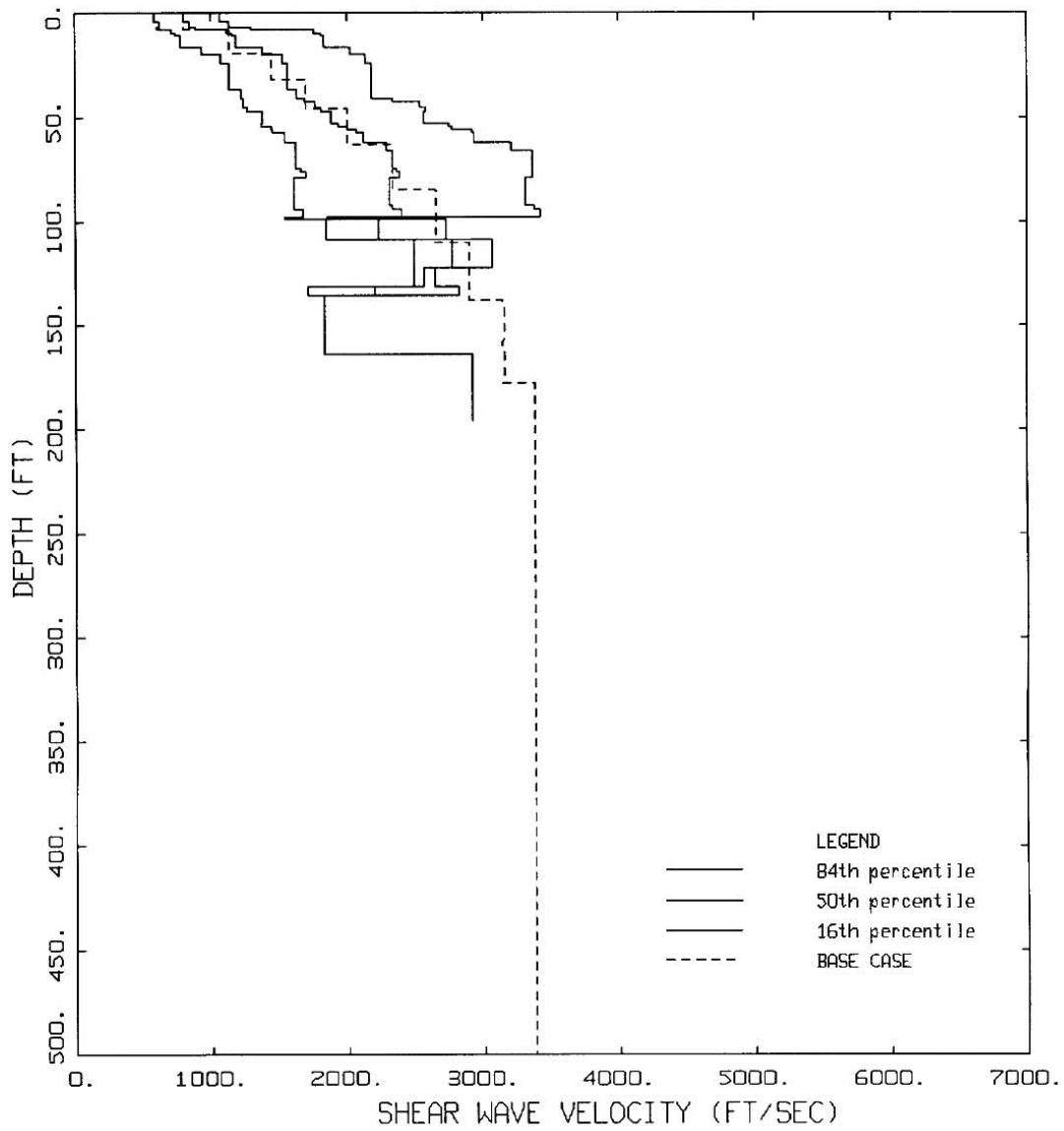
Figure 8. Comparison of median Alluvium shear-wave velocity profiles for San Francisco (Figure 4) and Los Angeles (Figure 5) areas.





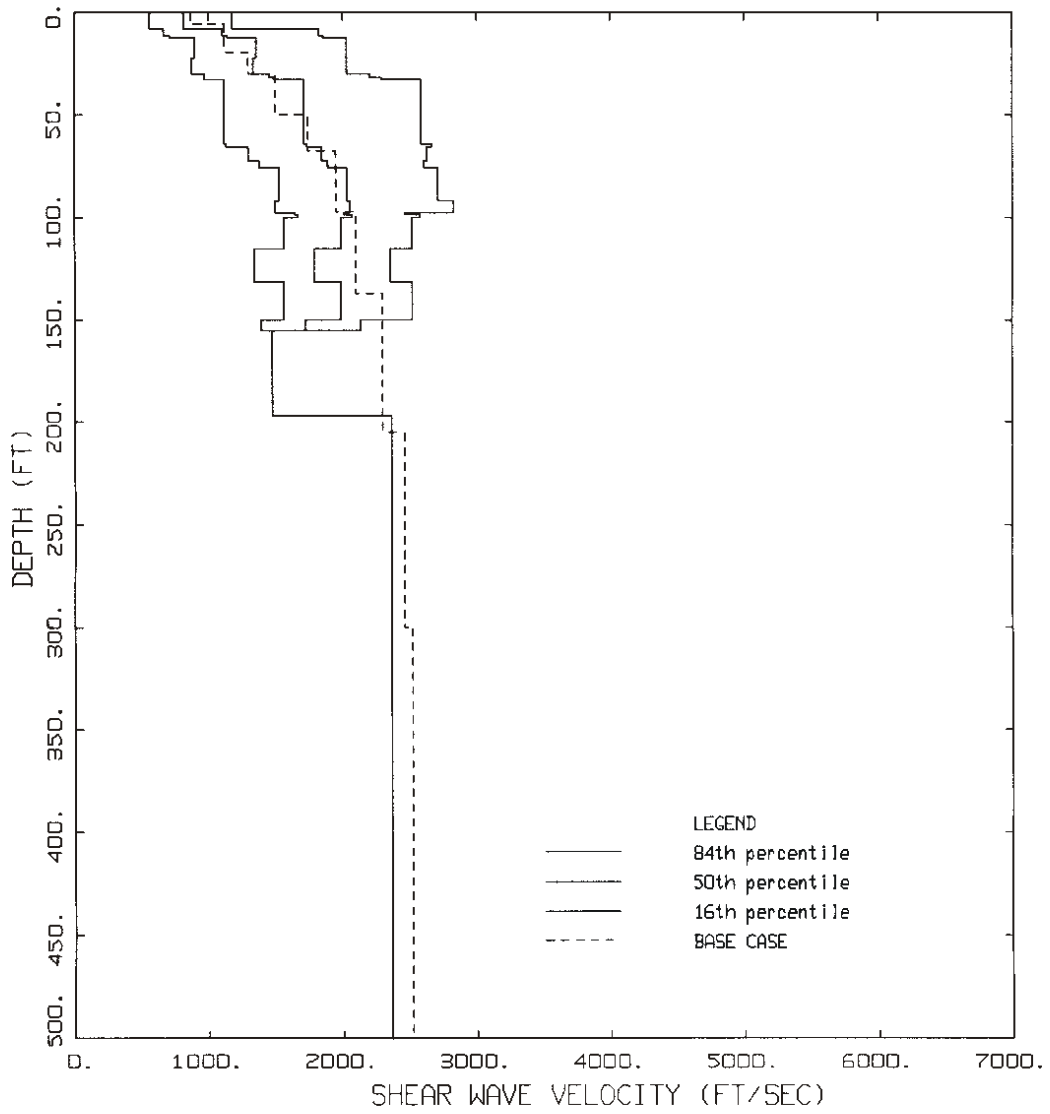
## SHEAR WAVE VELOCITY PROFILES KJF NORTH CALIFORNIA

Figure 9. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit  $K_{jp}$  Franciscan (Table 1).



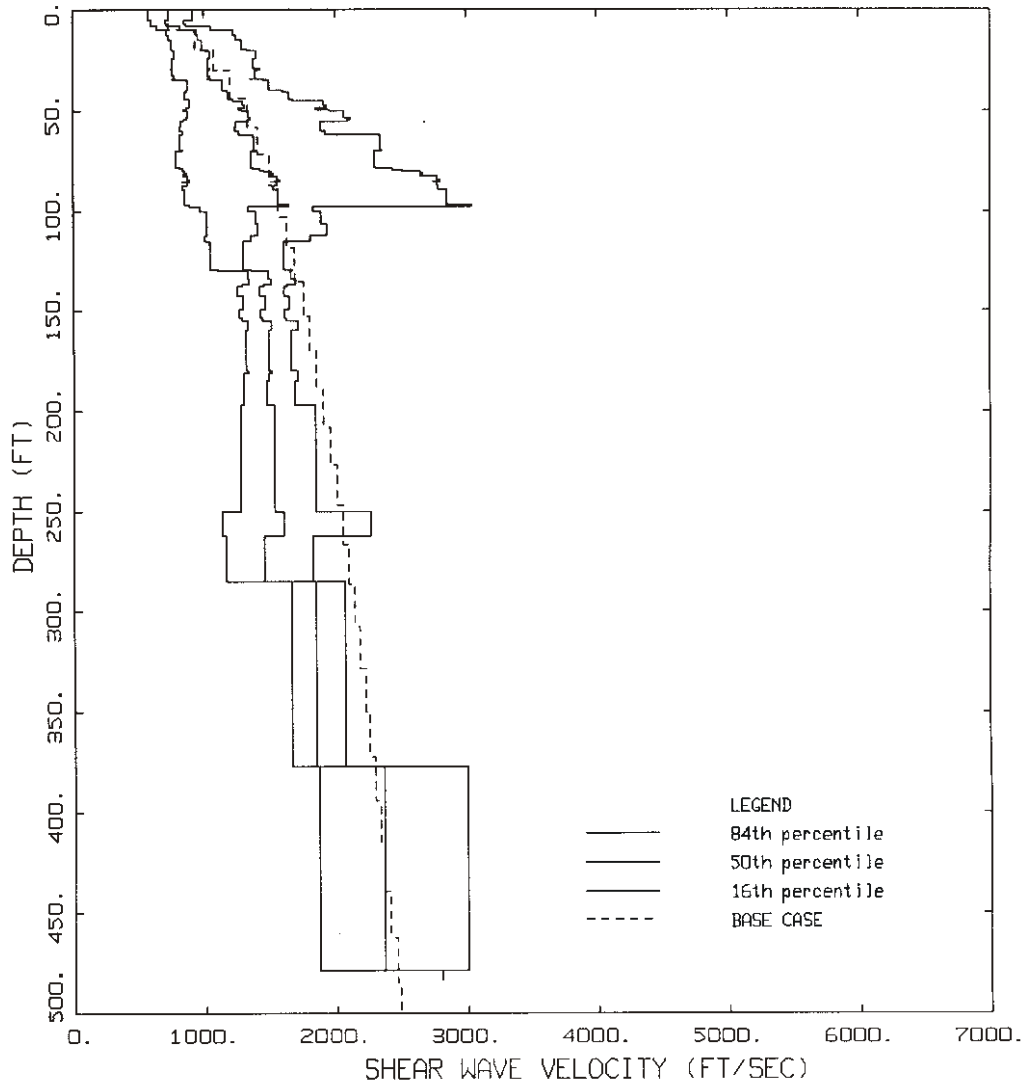
## SHEAR WAVE VELOCITY PROFILES TMzs NORTH CALIFORNIA

Figure 10. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit TM<sub>zs</sub>, Tertiary Bedrock (Table 1).



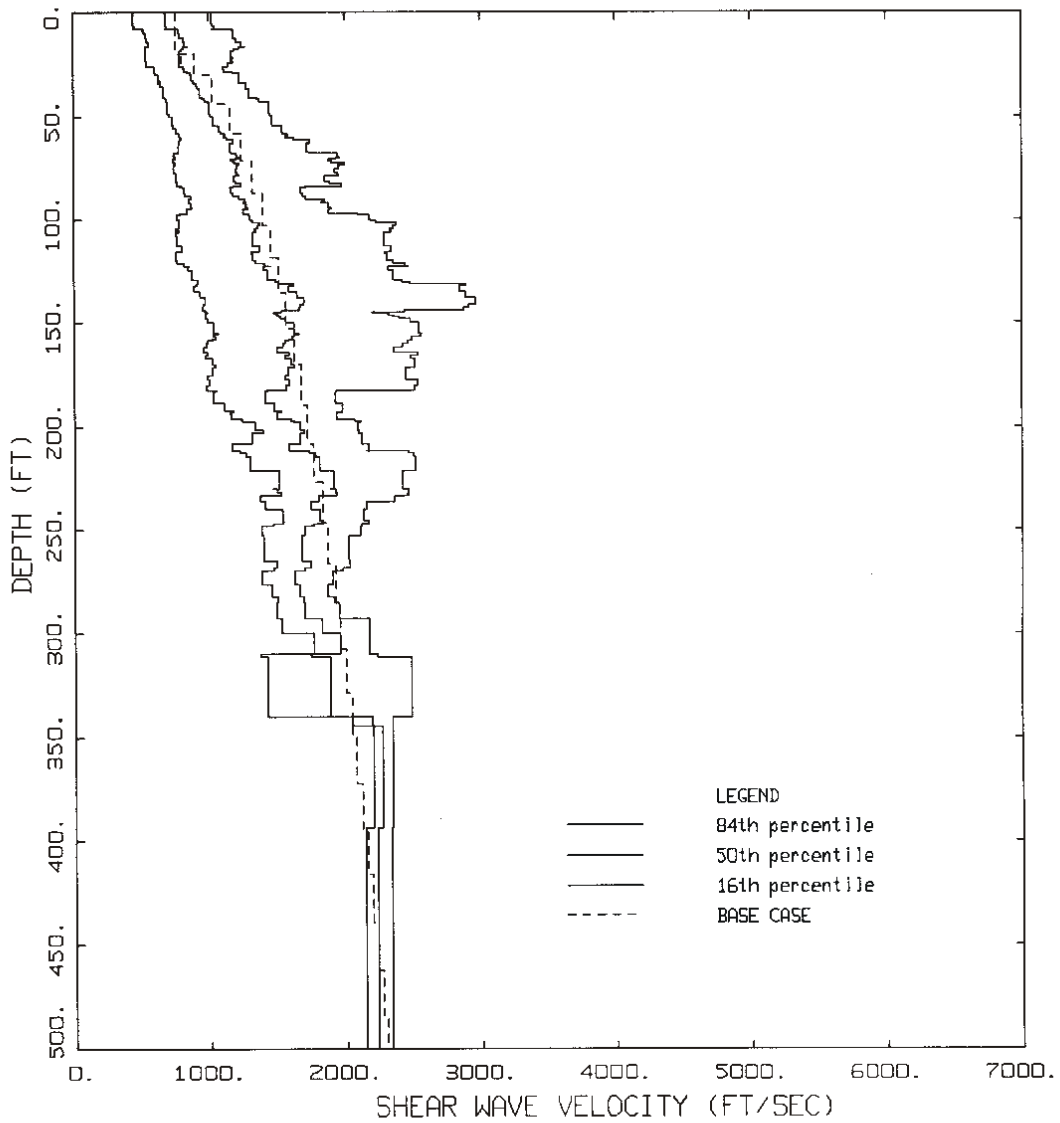
SHEAR WAVE VELOCITY PROFILES  
 QTs NORTH CALIFORNIA

Figure 11. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit QTs, Quaternary/Tertiary (Table 1).



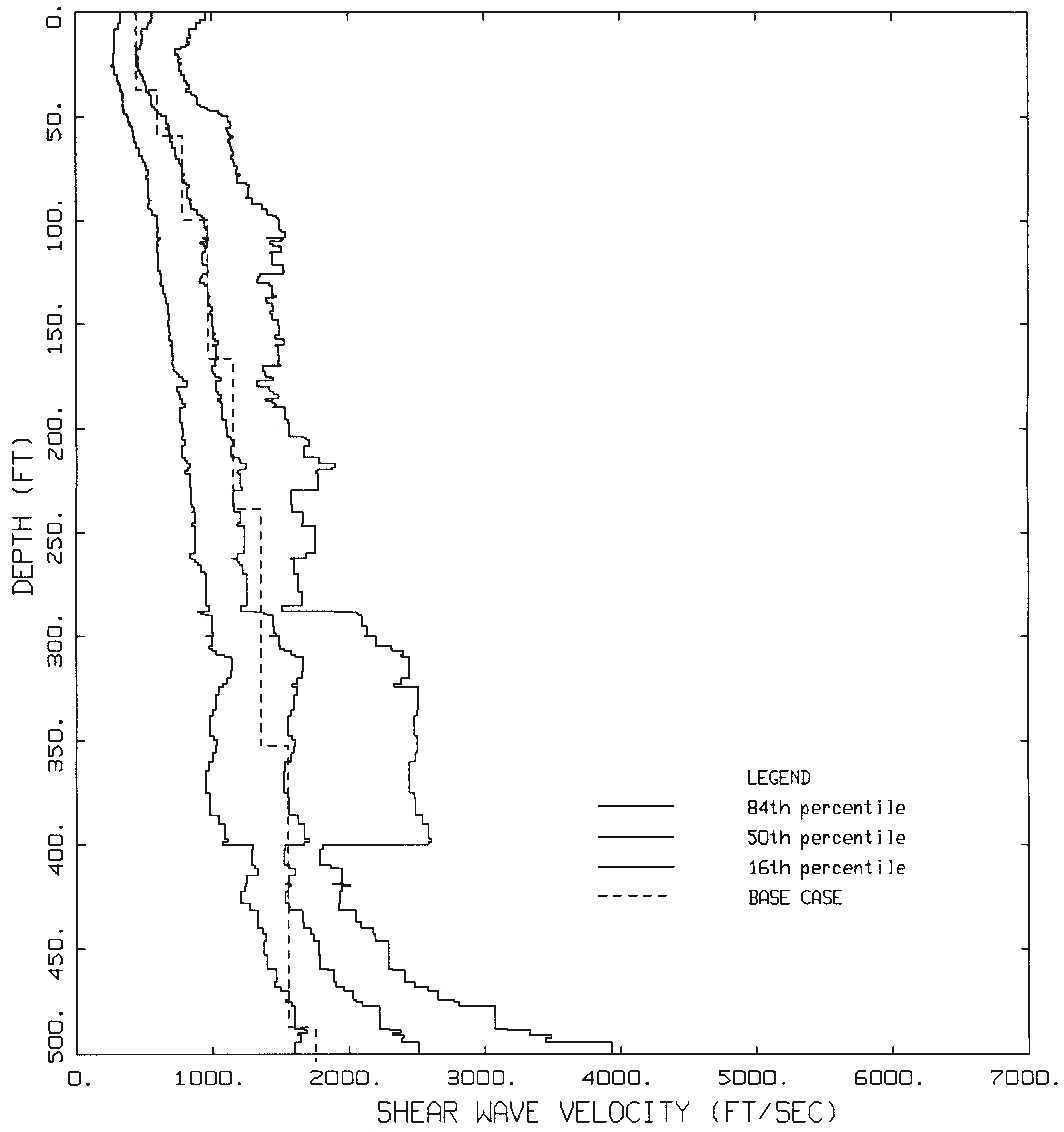
## SHEAR WAVE VELOCITY PROFILES Q<sub>oa</sub> NORTH CALIFORNIA

Figure 12. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit Q<sub>oa</sub>, Older Alluvium (Table 1).



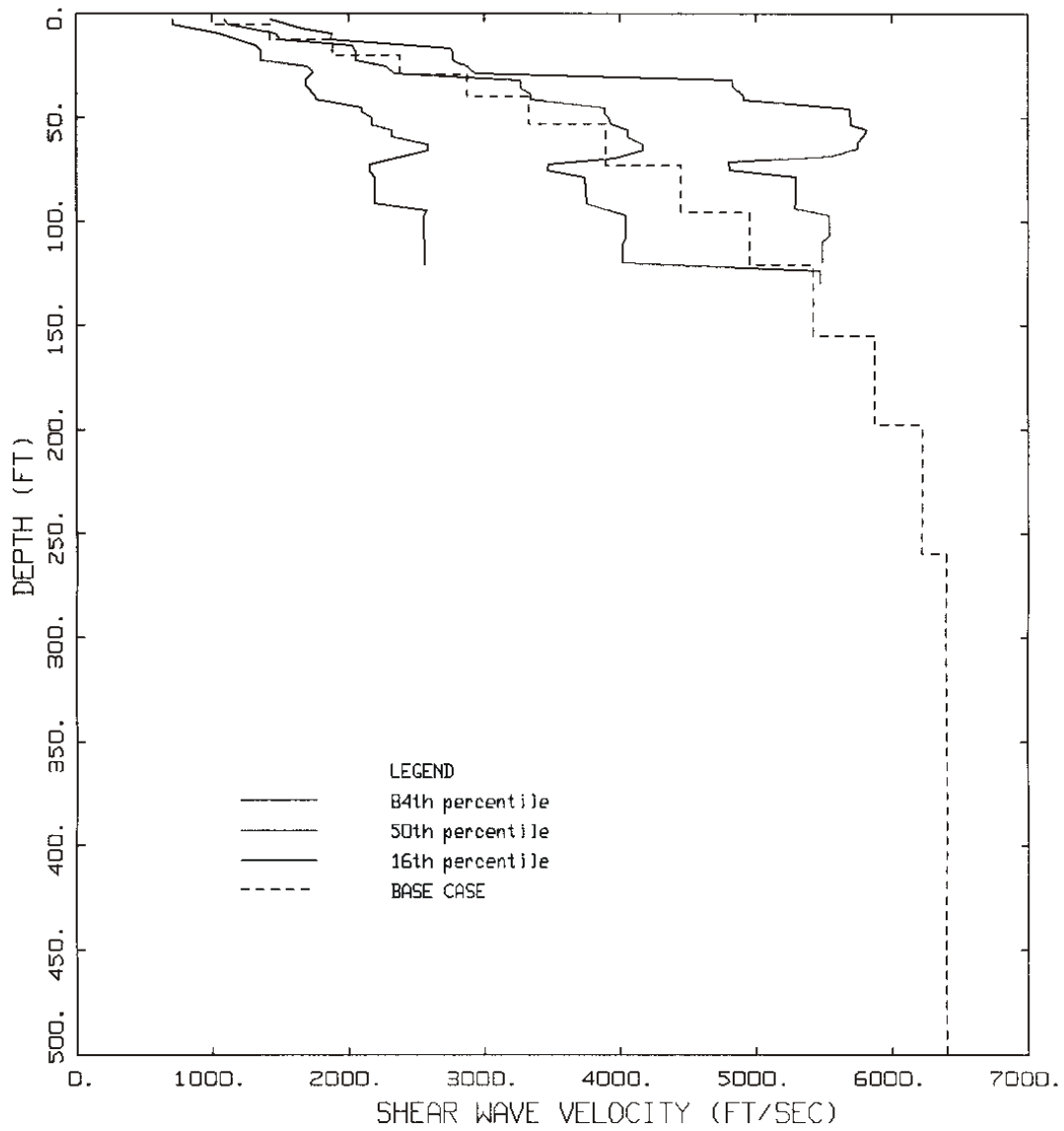
### SHEAR WAVE VELOCITY PROFILES Qa1 NORTH CALIFORNIA

Figure 13. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit Qa1, Quaternary Alluvium (Table 1).



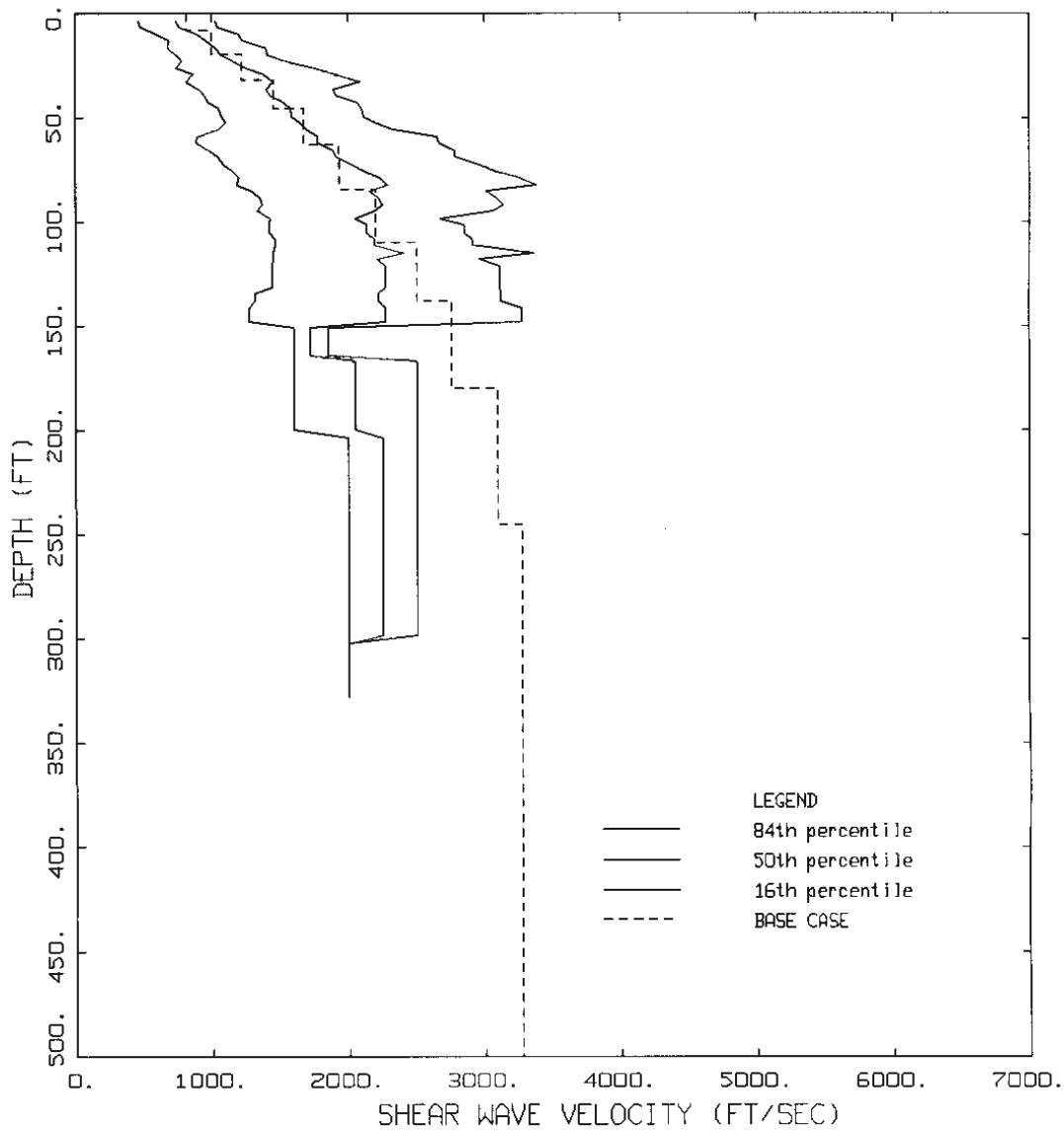
SHEAR WAVE VELOCITY PROFILES  
 Q<sub>m</sub> NORTH CALIFORNIA

Figure 14. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit Q<sub>m</sub>, Bay Mud (Table 1).



SHEAR WAVE VELOCITY PROFILES  
Mxb (GRANITE) LOS ANGELES AREA

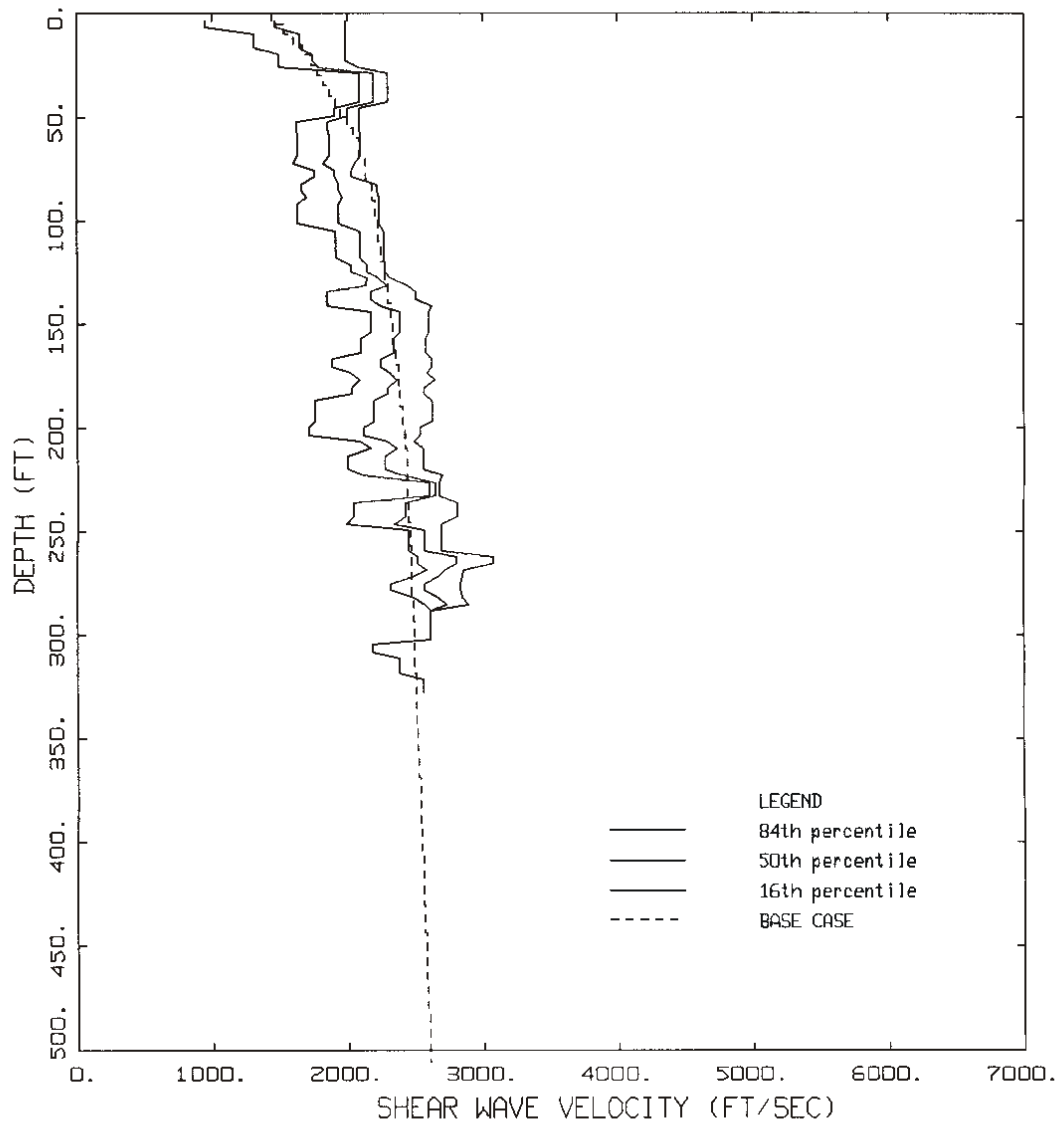
Figure 15. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the Los Angeles area surface geologic unit  $M_{xb}$ , Granite (Table 1).



SHEAR WAVE VELOCITY PROFILES  
 T<sub>s</sub> (TERTIARY) LOS ANGELES AREA

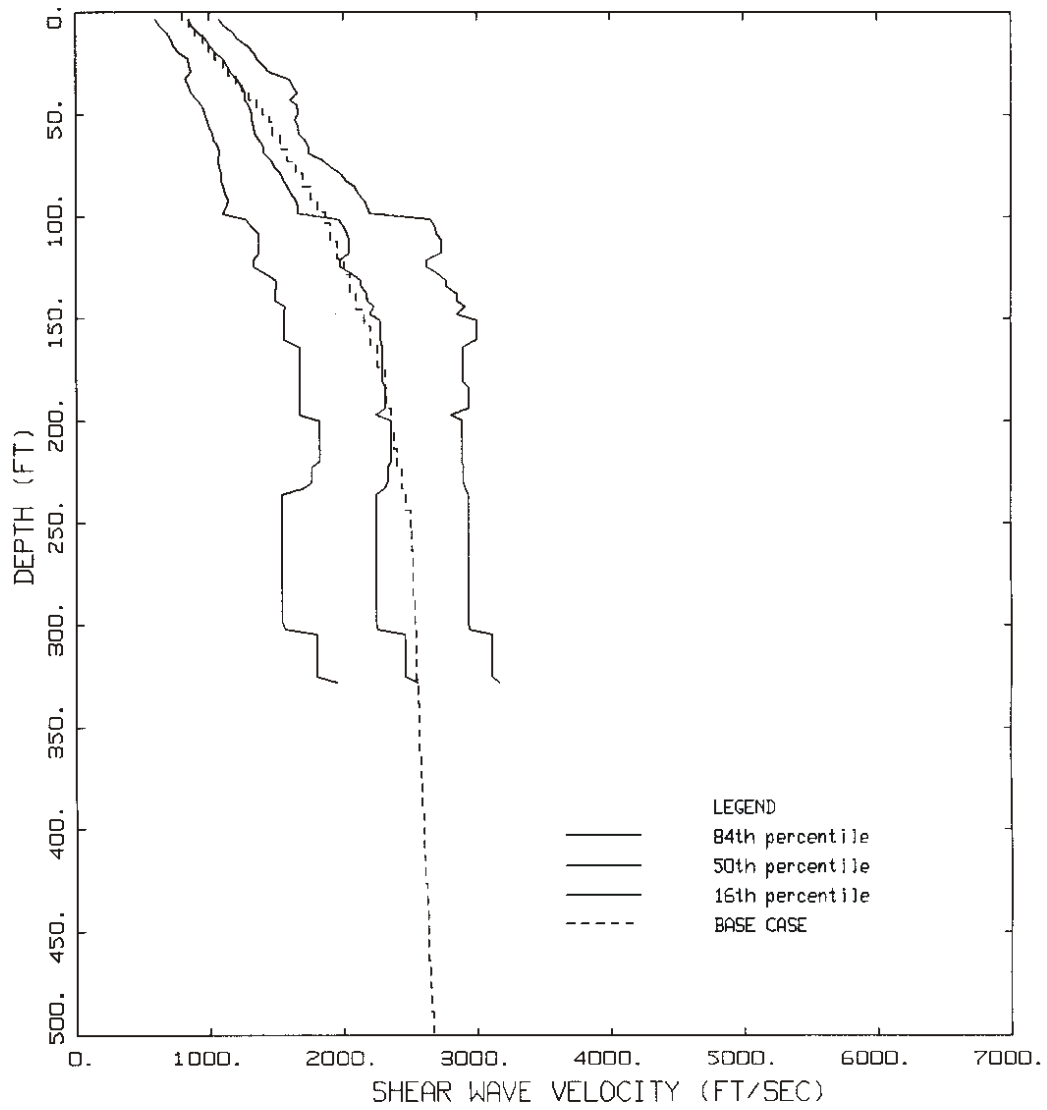
Figure 16. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the Los Angeles area surface geologic unit T<sub>s</sub>, Tertiary (Table 1).





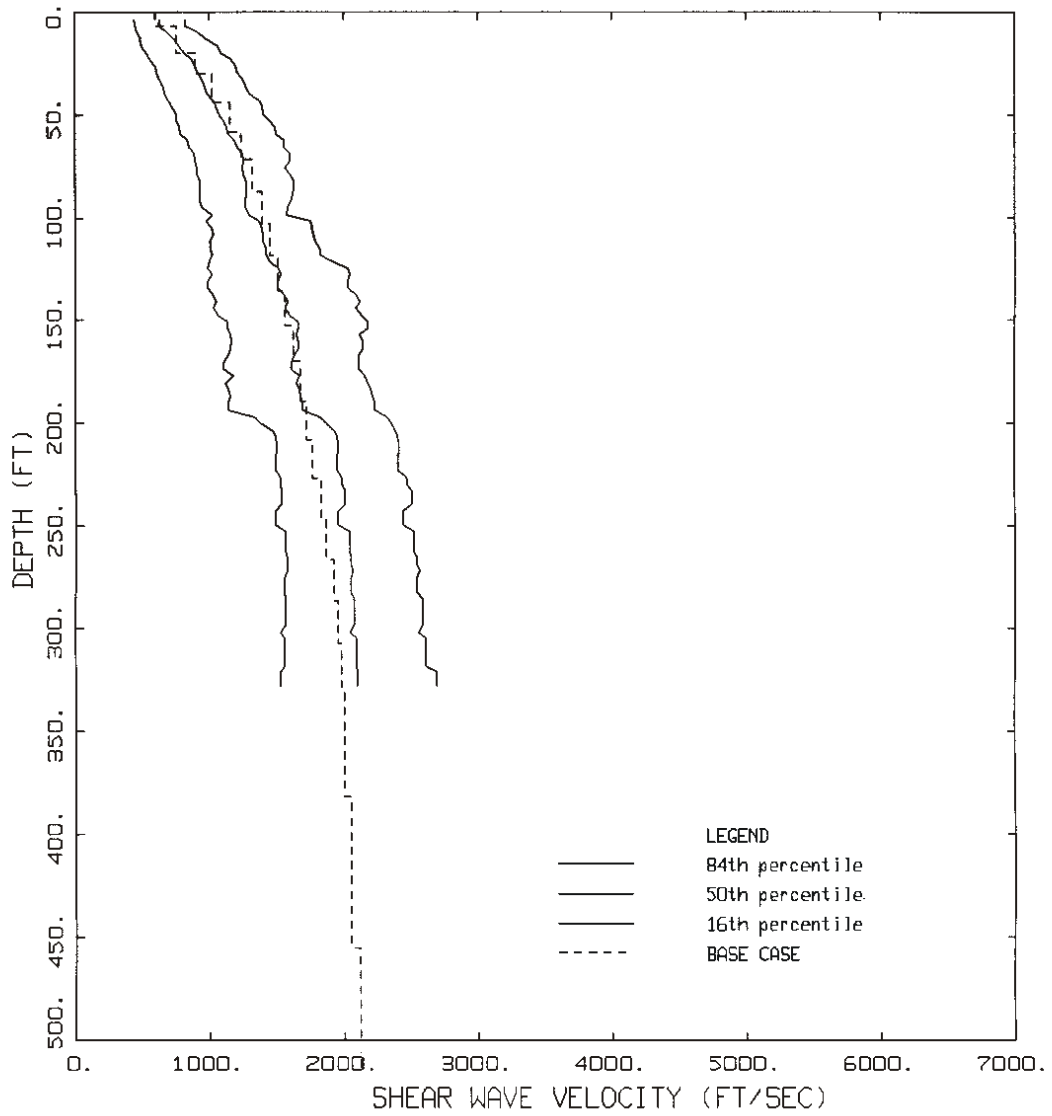
SHEAR WAVE VELOCITY PROFILES  
 T<sub>s</sub> (SAUGUS) LOS ANGELES AREA

Figure 17. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the San Francisco Bay area surface geologic unit T<sub>s</sub>, Saugus (Table 1).



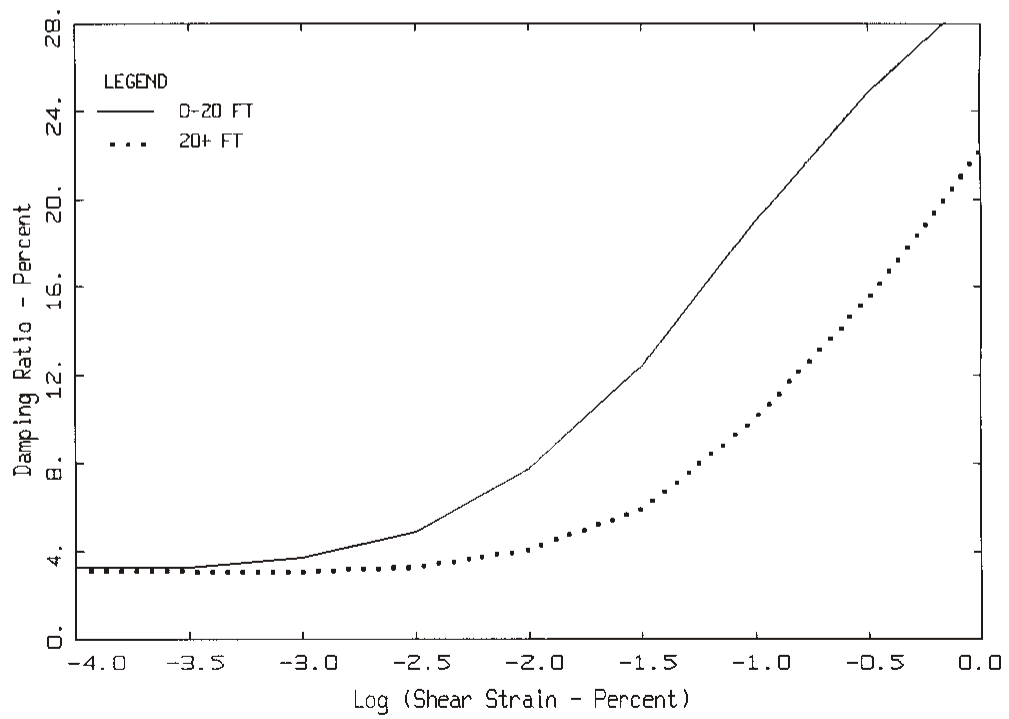
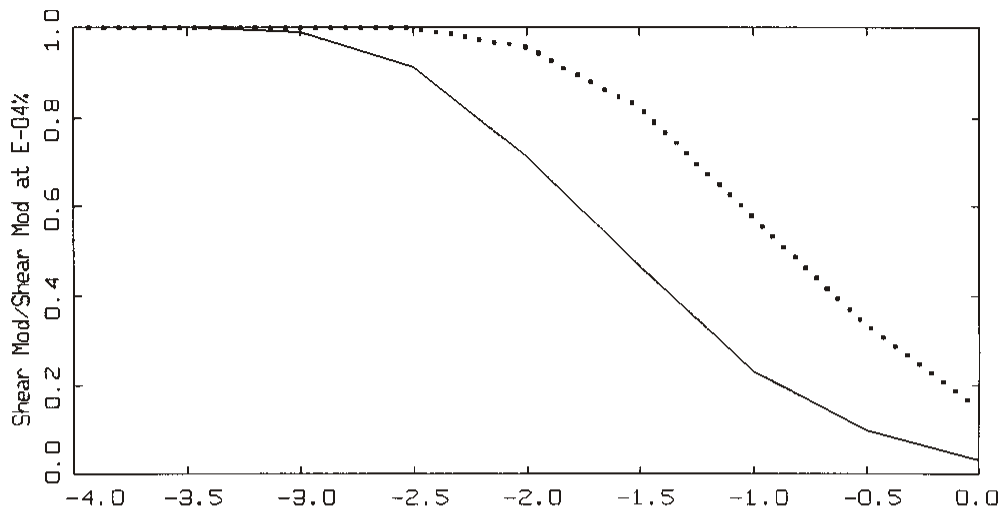
### SHEAR WAVE VELOCITY PROFILES Q<sub>o</sub> LOS ANGELES AREA

Figure 18. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the Los Angeles area surface geologic unit Q<sub>o</sub>, Older Alluvium (Table 1).



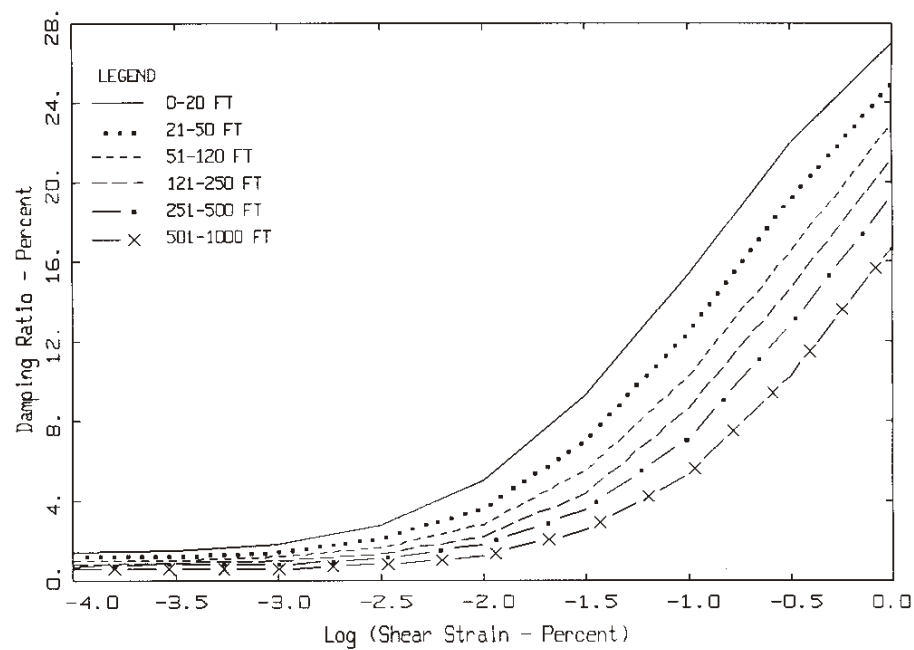
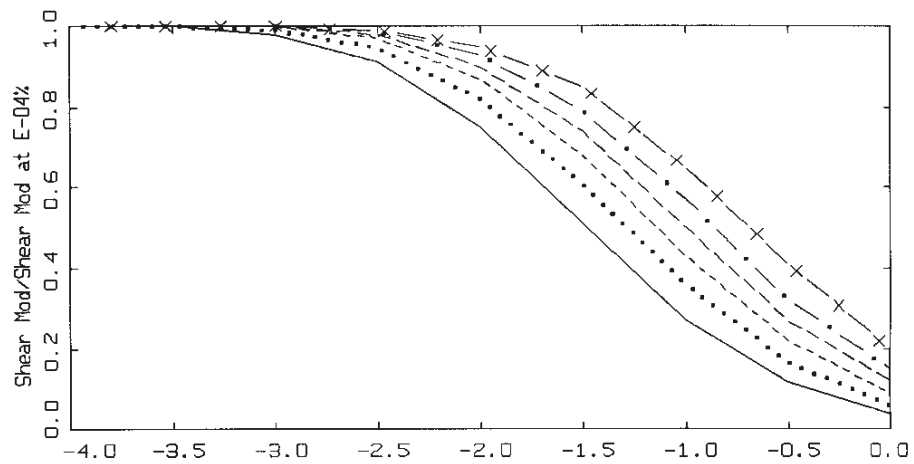
SHEAR WAVE VELOCITY PROFILES  
 Q<sub>y</sub> LOS ANGELES AREA

Figure 19. Median and  $\pm 1 \sigma$  shear-wave velocity profiles for the Los Angeles area surface geologic unit Q<sub>y</sub> Younger Alluvium (Table 1).



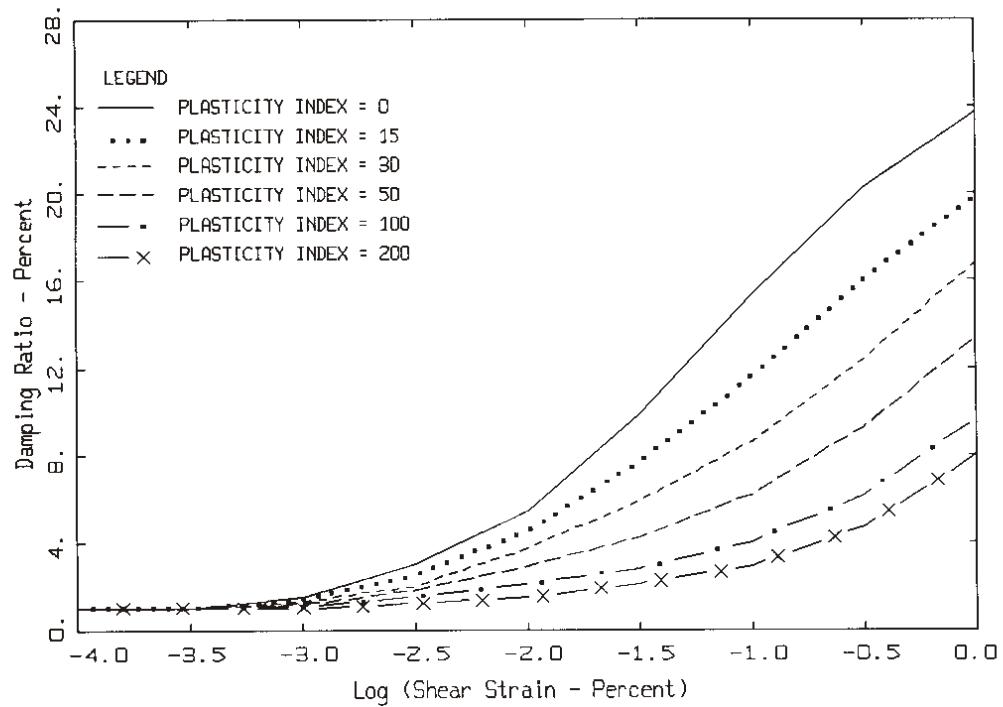
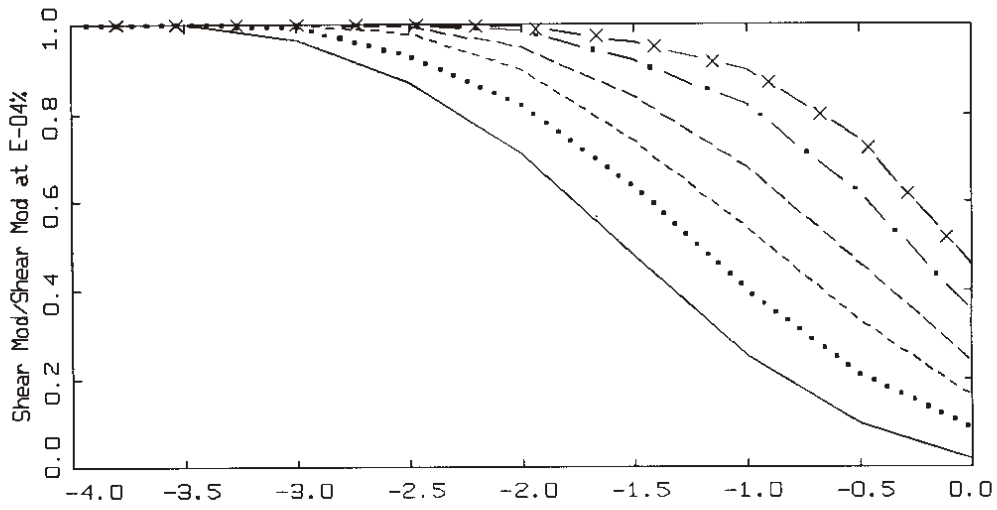
MODULUS REDUCTION AND DAMPING CURVES FOR ROCK

Figure 20. Generic G/Gmax and hysteretic damping curves for rock site conditions.



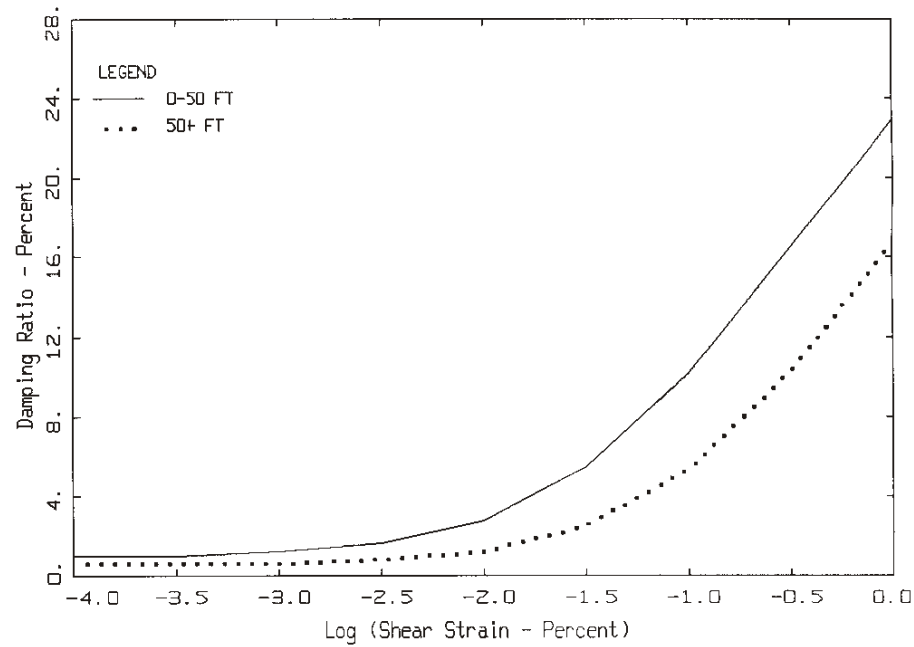
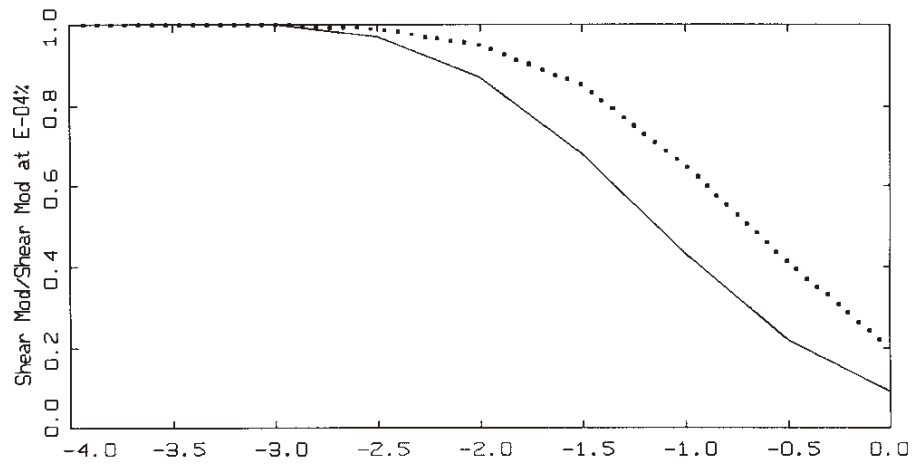
MODULUS REDUCTION AND DAMPING CURVES FOR SAND

Figure 21. Generic  $G/G_{max}$  and hysteretic damping curves for North Coast cohesionless soil site conditions (EPRI, 1993).



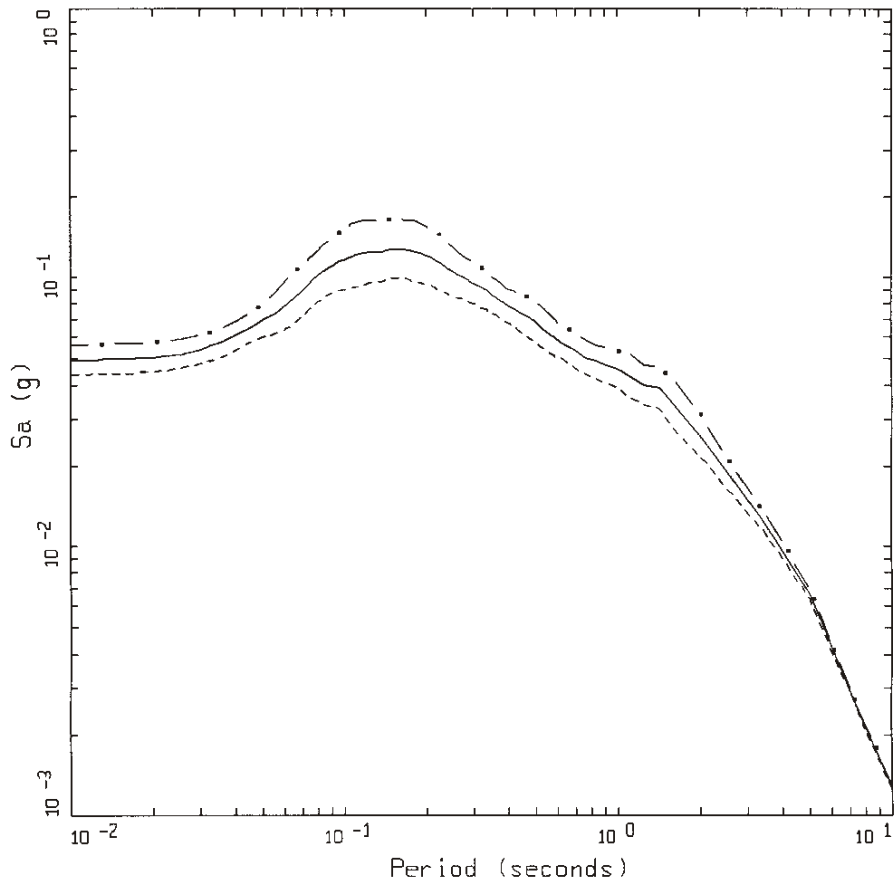
VUCETIC/DOBRY MODULUS REDUCTION AND DAMPING CURVES

Figure 22. Generic  $G/G_{max}$  and hysteretic damping curves for cohesive soil site conditions (Vucetic and Dobry, 1991).



MODULUS REDUCTION AND DAMPING CURVES FOR SAND

Figure 23. Generic G/Gmax and hysteretic damping curves for Peninsular Range cohesionless soil site conditions (Silva et al., 1997).

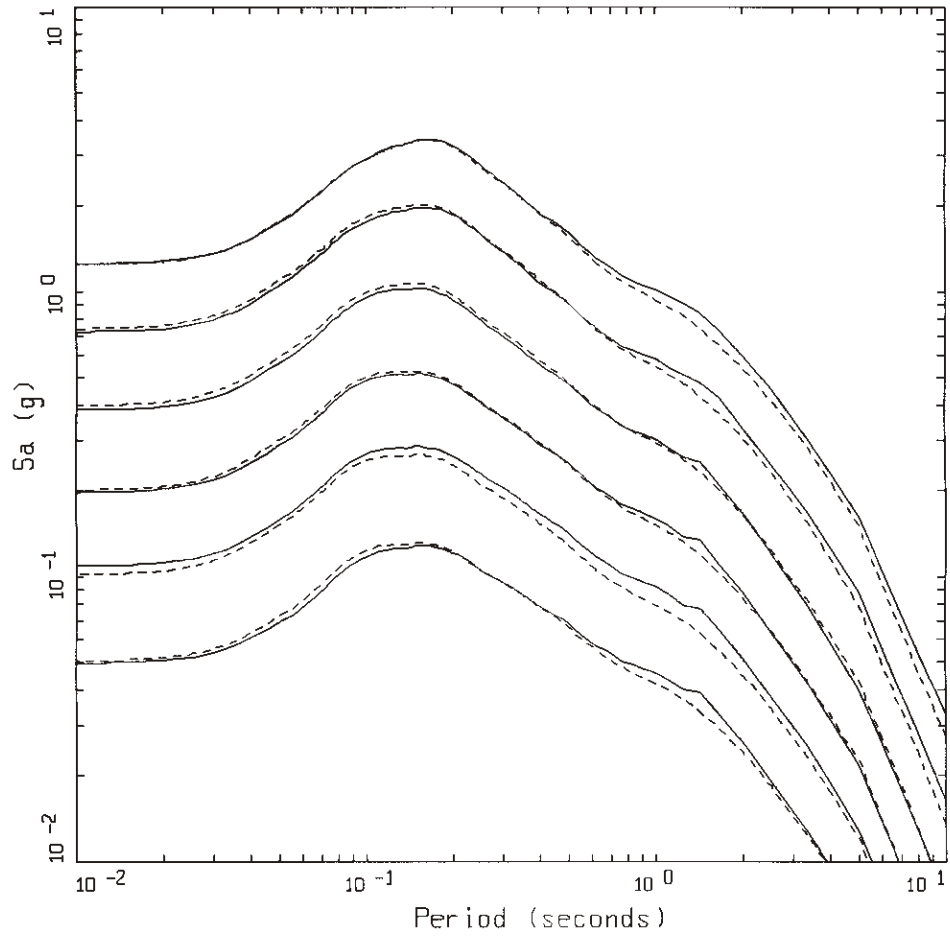


FRANCISCAN OUTCROP, 0.05 G  
 M 6.5, STRESS DROP = 60 BARS

- LEGEND
- . - 84TH PERCENTILE, PARAMETRIC UNCERTAINTY; PGA = 0.057 G
  - 50TH PERCENTILE, PARAMETRIC UNCERTAINTY; PGA = 0.050 G
  - - - 16TH PERCENTILE, PARAMETRIC UNCERTAINTY; PGA = 0.044 G

Figure 24. Median and  $\pm 1 \sigma$  5% damped baserock (Franciscan) motions for 5%g (Table 4):  $M = 6.5$ , stress drop = 60 bars. Parametric variation includes top 250 ft of the profile (Figure 15) and nonlinear properties (Figure 20).

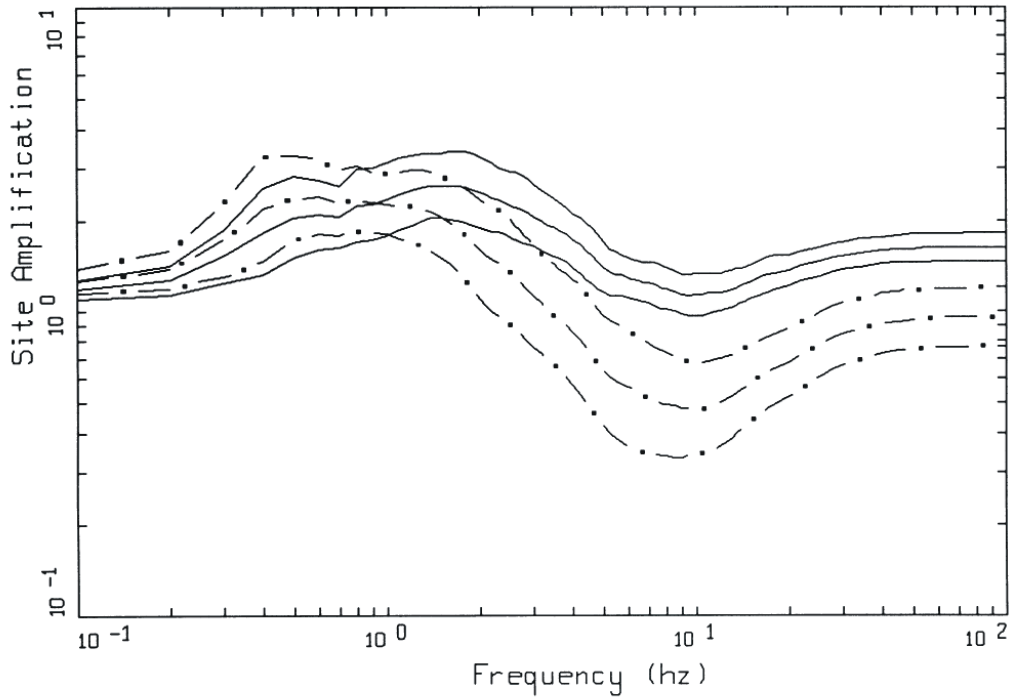




REFERENCE ROCK OUTCROP  
 M 6.5, STRESS DROP = 60 BARS

LEGEND  
 — FRANCISCAN OUTCROP  
 - - - GRANITE OUTCROP

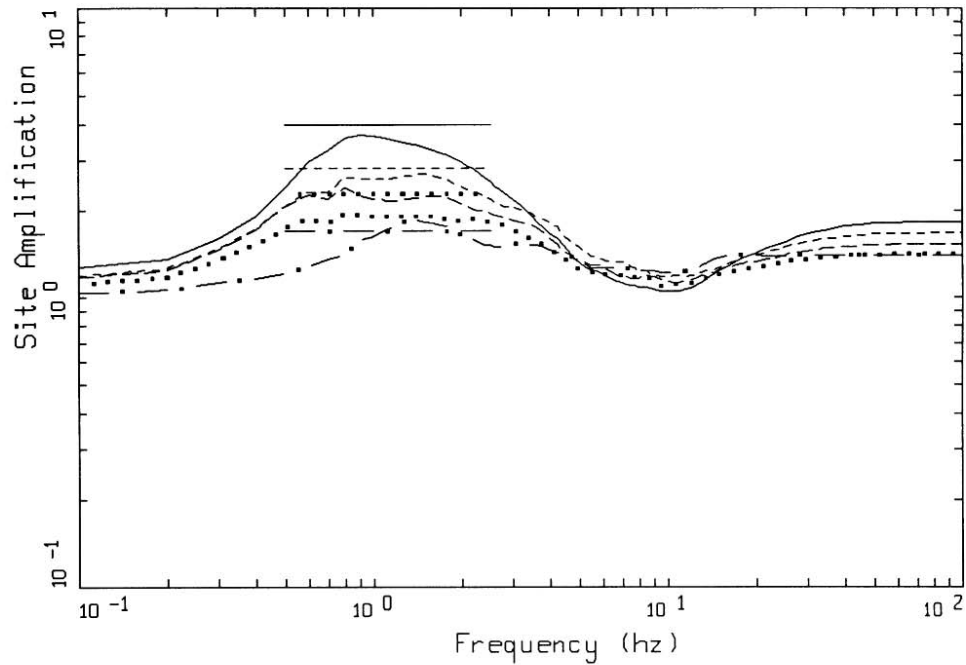
Figure 25. Comparison of median 5% damped response spectra computed for San Francisco (solid) and Los Angeles (dashed) area baserock site conditions for suite of outcrop peak acceleration values (Table 4):  $M=6.5$ , stress drop: 60 bars.



QAL AMPLIFICATION (D), SF  
DEPTH RANGE 30 - 1000 FEET

LEGEND	
————	84TH PERCENTILE, REFERENCE FRANCISCAN, 0.05 G
————	50TH PERCENTILE, REFERENCE FRANCISCAN, 0.05 G
————	16TH PERCENTILE, REFERENCE FRANCISCAN, 0.05 G
- · -	84TH PERCENTILE, REFERENCE FRANCISCAN, 0.40 G
- · -	50TH PERCENTILE, REFERENCE FRANCISCAN, 0.40 G
- · -	16TH PERCENTILE, REFERENCE FRANCISCAN, 0.40 G

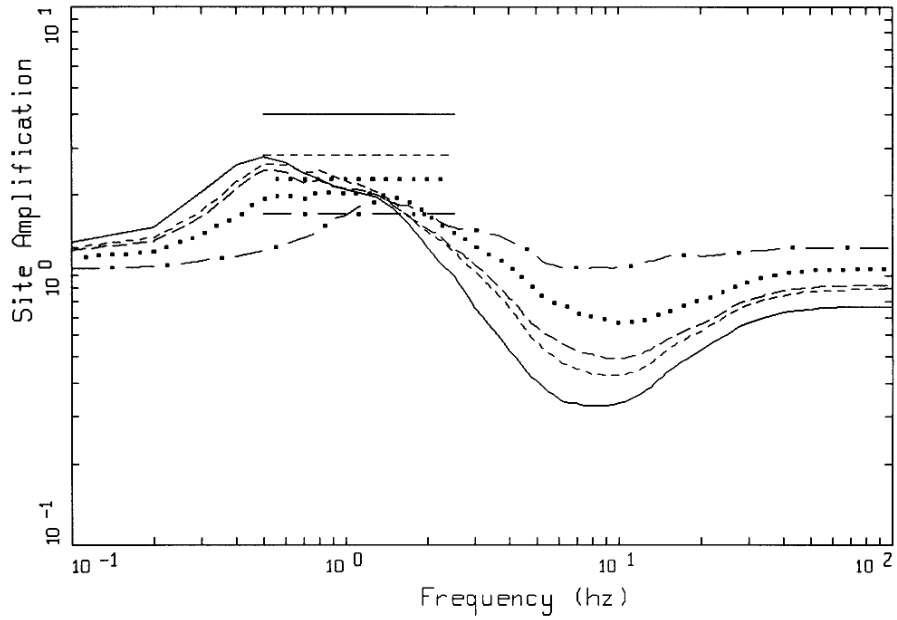
Figure 26. Comparison of median and  $\pm 1 \sigma$  amplification factors (5% damped response spectra) for San Francisco area Quaternary Alluvium ( $Q_4$ ) depth category 4 (30 to 1,000 ft) for reference Franciscan rock outcrop median peak acceleration values of 0.05g and 0.40g.



AMPLIFICATION: 5% DAMPED RESPONSE SPECTRA  
 REFERENCE FRANCISCAN 0.05 G

- LEGEND
- BAY MUD, 150-350ft (5% Damped Response Spectra, median)
  - QAL, 350-650ft (5% Damped Response Spectra, median)
  - - - - QOA, 350-650ft (5% Damped Response Spectra, median)
  - ..... QUATERNARY/TERTIARY, 350-650ft (5% Damped Response Spectra, median)
  - · - · TERTIARY (5% Damped Response Spectra, median)
  - BAY MUD (Borcherdt (1992) Empirical Fourier Amplitude Spectra, average)
  - QAL (Borcherdt (1992) Empirical Fourier Amplitude Spectra, average)
  - ..... QUATERNARY/TERTIARY (Borcherdt (1992) Empirical Fourier Amplitude Spectra, average)
  - · - · TERTIARY (Borcherdt (1992) Empirical Fourier Amplitude Spectra, average)

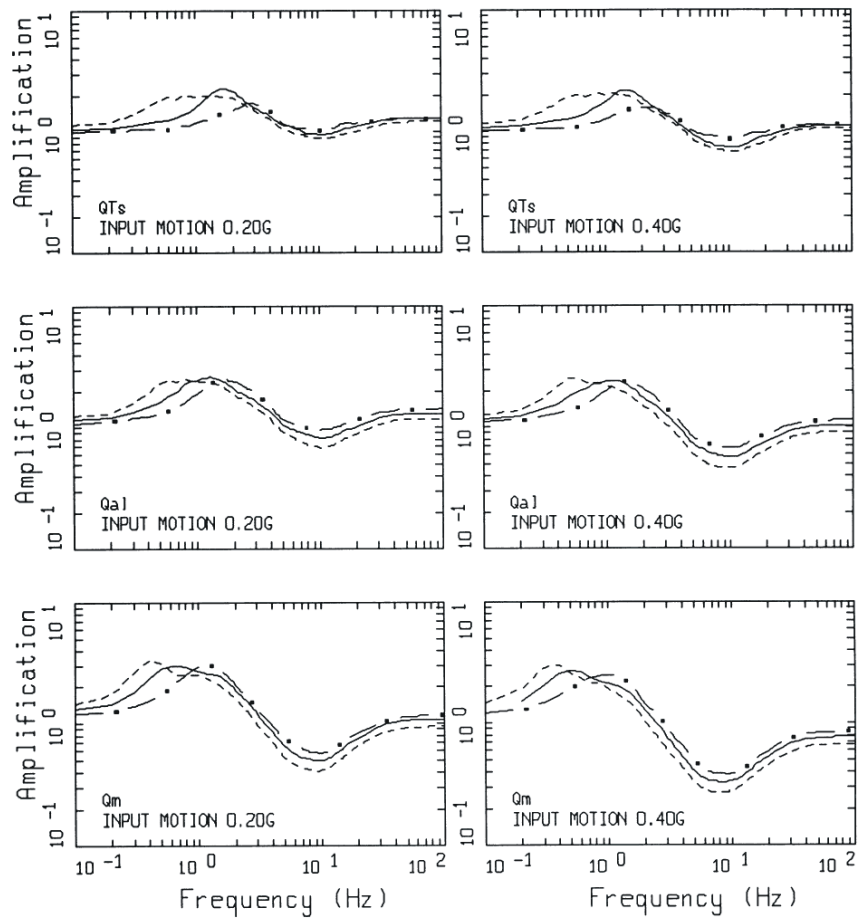
Figure 27. Comparison of median amplification factors (5% damped response spectra) computed for reference Franciscan outcrop peak acceleration of 0.05g with empirical factors (smoothed Fourier amplitude spectra; Borcherdt and Glassmoyer, 1992). Empirical factors were computed using low levels of loading (generally  $\leq 0.10g$ ).



AMPLIFICATION: 5% DAMPED RESPONSE SPECTRA  
 REFERENCE FRANCISCAN 0.40 G

- LEGEND
- BAY MUD, 150-350ft (5% Damped Response Spectra, median)
  - QAL, 350-650ft (5% Damped Response Spectra, median)
  - - - - QOA, 350-650ft (5% Damped Response Spectra, median)
  - ..... QUATERNARY/TERTIARY, 350-650ft (5% Damped Response Spectra, median)
  - · - · TERTIARY (5% Damped Response Spectra, median)
  - BAY MUD (Empirical Fourier Amplitude Spectra, average)
  - QAL (Empirical Fourier Amplitude Spectra, average)
  - ..... QUATERNARY/TERTIARY (Empirical Fourier Amplitude Spectra, average)
  - · - · TERTIARY (Empirical Fourier Amplitude Spectra, average)

Figure 28. Comparison of median amplification factors (5% damped response spectra) computed for reference Franciscan outcrop peak acceleration of 0.40g with empirical factors (smoothed Fourier amplitude spectra; Borchardt and Glassmoyer, 1992). Empirical factors were computed using low levels of loading (generally  $\leq 0.10g$ ).



SF AMPLIFICATION

Figure 29. Median amplification factors computed for  $QT_s$ ,  $Q_{a1}$ ,  $Q_m$ , for different depth categories: 30 ft to 150 ft, dash dots; 150 ft to 350 ft, solid; 350 ft to 650 ft, dashes.

### SF AMPLIFICATION

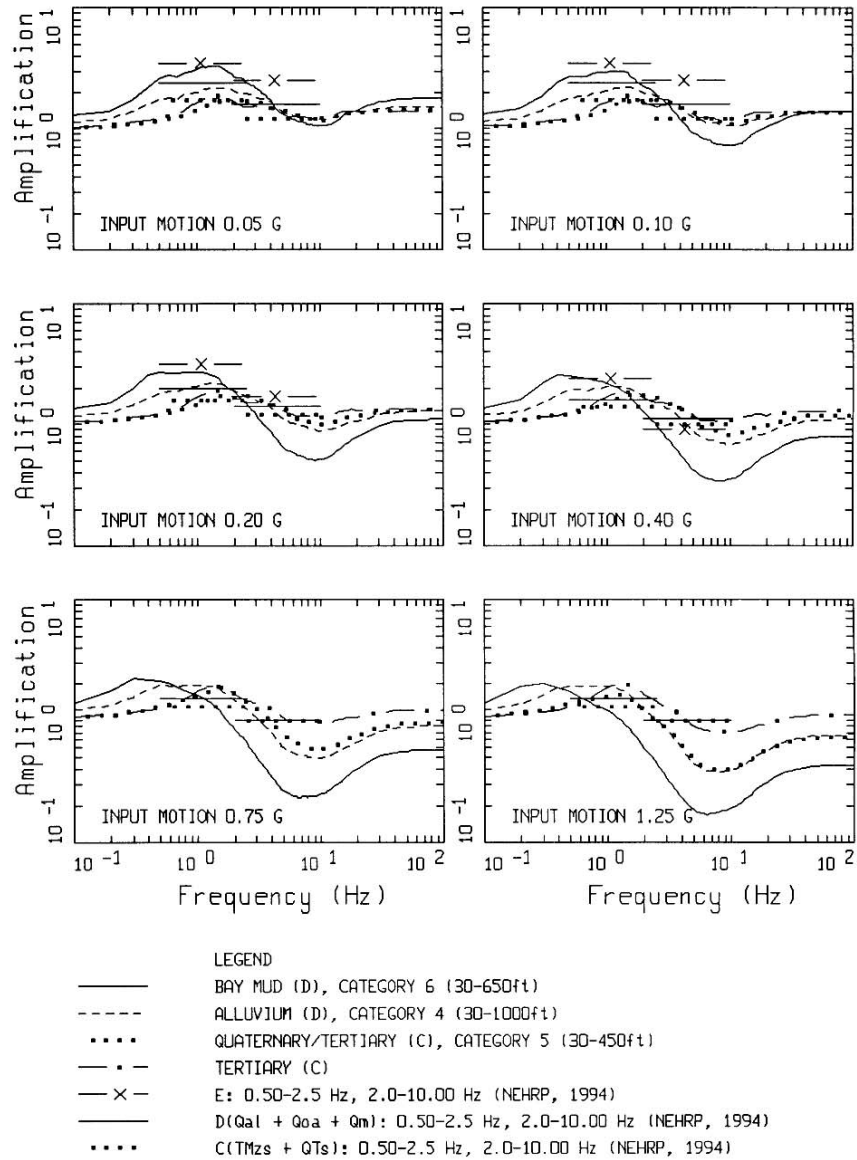


Figure 30. Comparison of median amplification factors with NEHRP provisions.

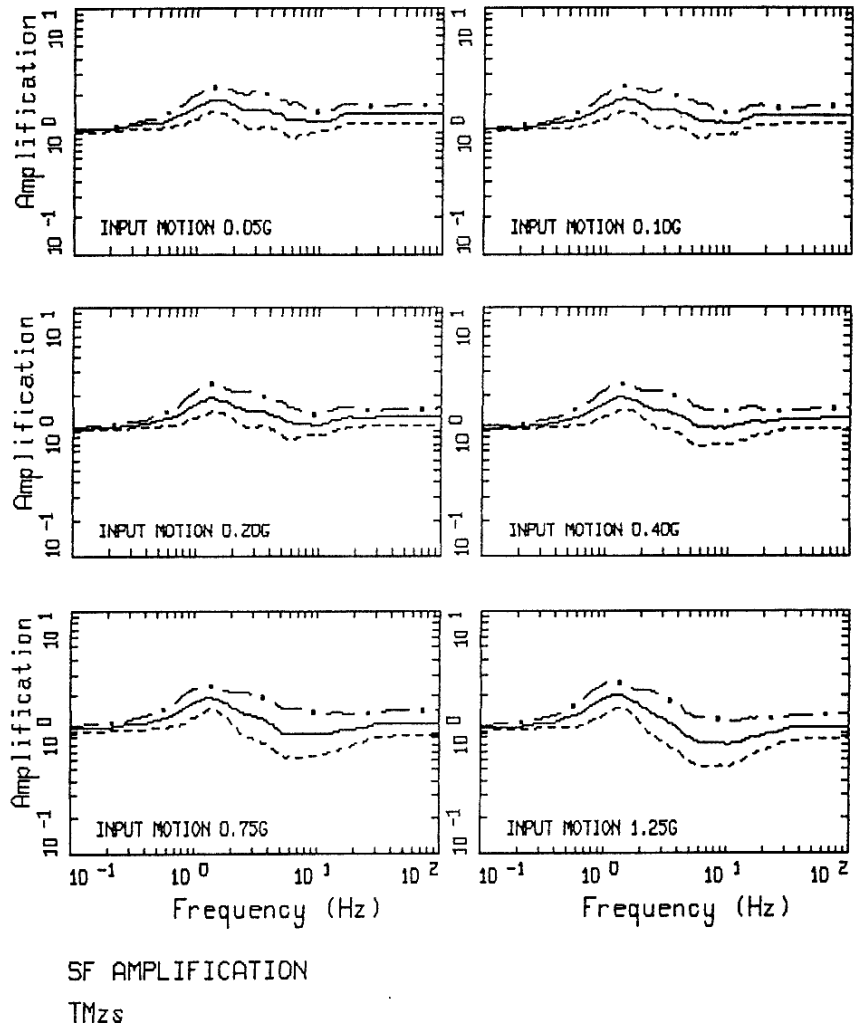
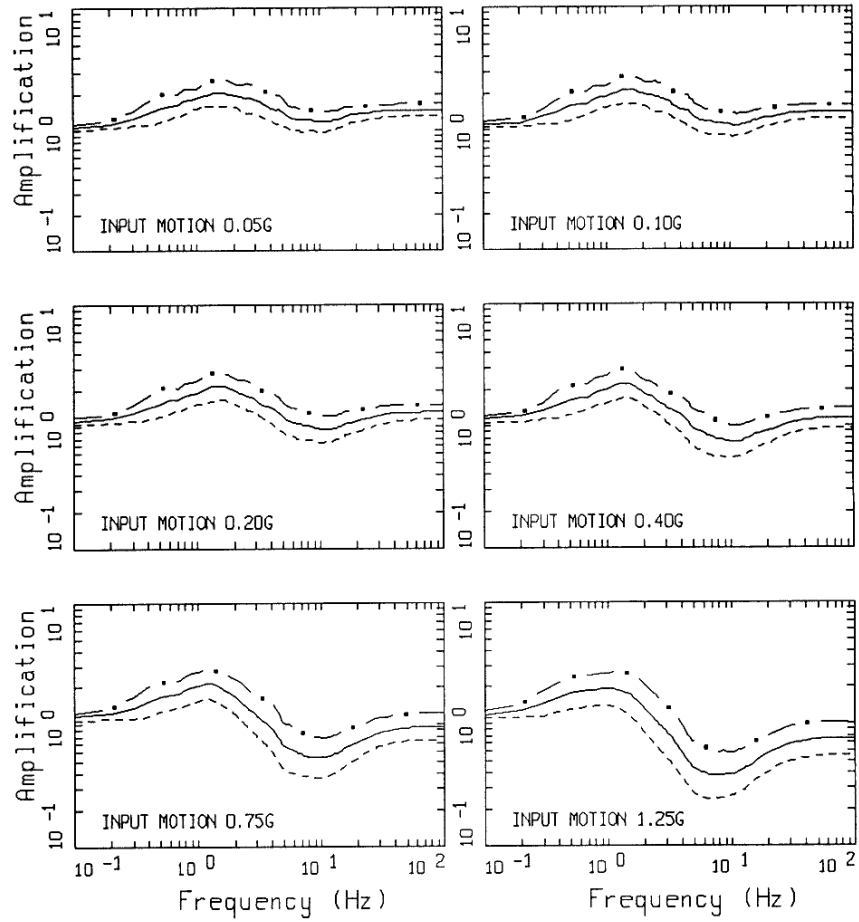


Figure 31. Median and  $\pm 1 \sigma$  amplification factors computed for San Francisco area surficial geologic unit TM<sub>zs</sub> (Table 1).



SF AMPLIFICATION  
 QT<sub>s</sub> (30 - 650 ft)

Figure 32. Median and  $\pm 1 \sigma$  amplification factors computed for San Francisco area surficial geologic unit QT<sub>s</sub> (Table 1).



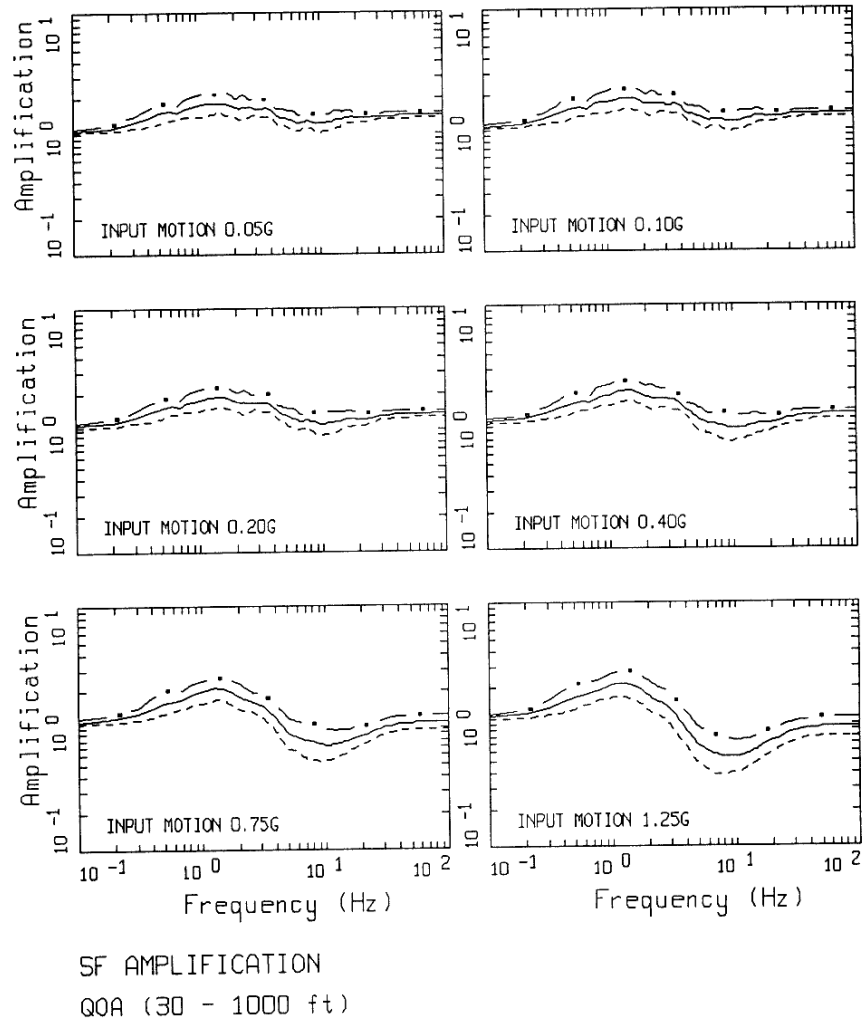
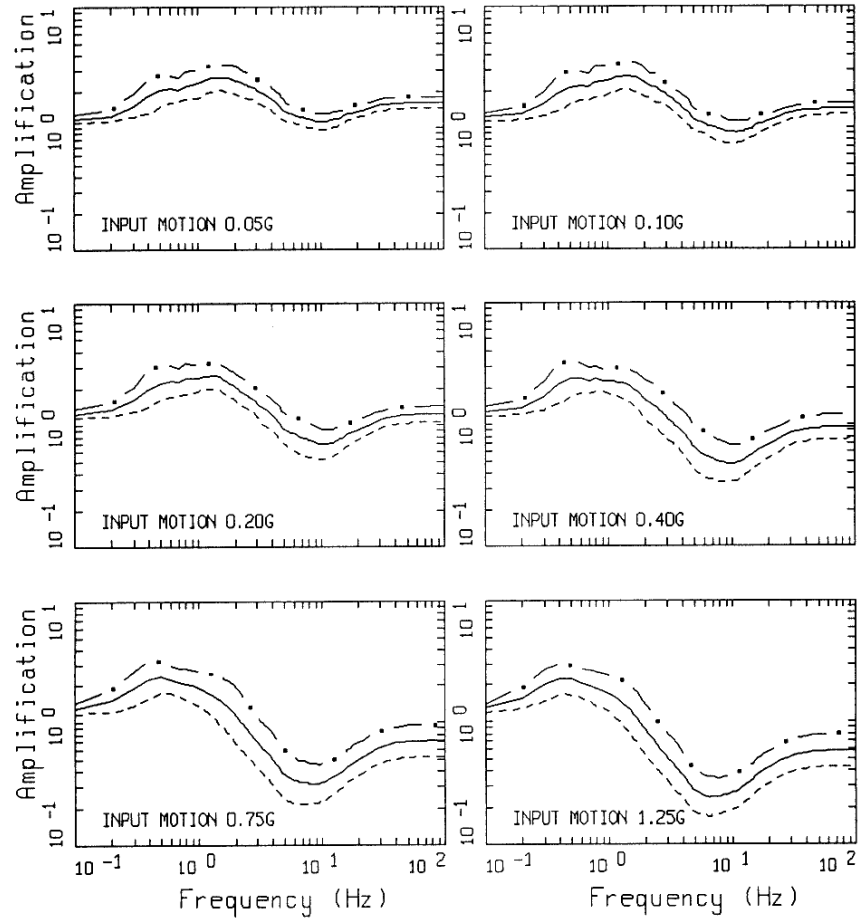
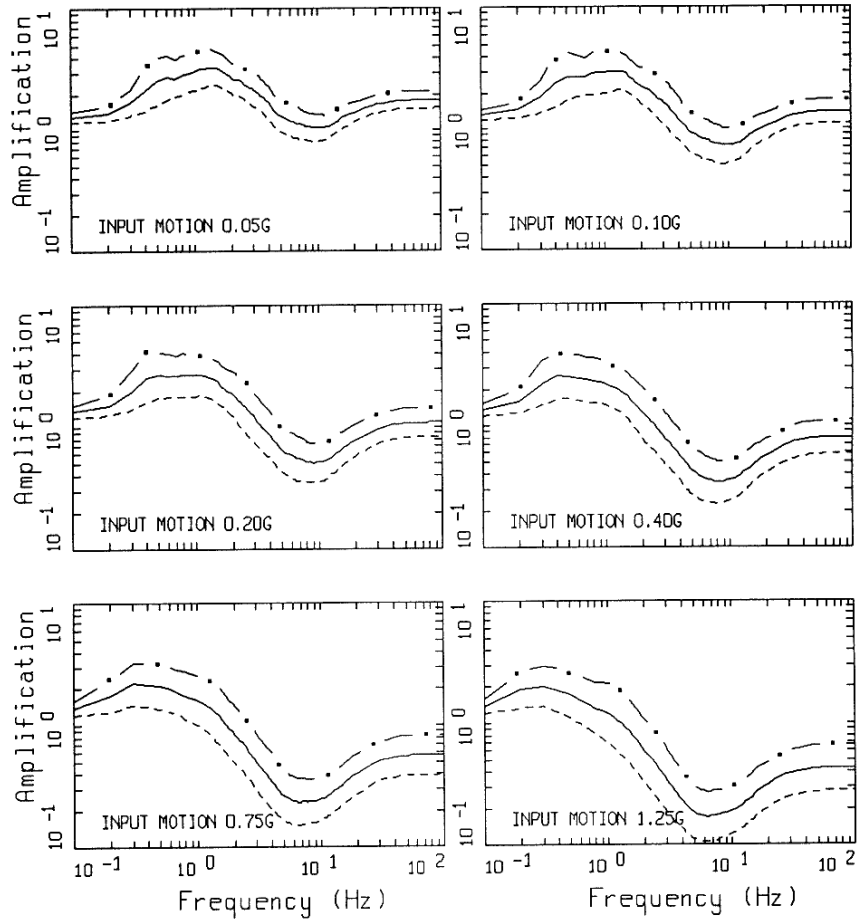


Figure 33. Median and  $\pm 1 \sigma$  amplification factors computed for San Francisco area surficial geologic unit  $Q_{0a}$  (Table 1).



SF AMPLIFICATION  
 QAL (30 - 1000 ft)

Figure 34. Median and  $\pm 1 \sigma$  amplification factors computed for San Francisco area surficial geologic unit  $Q_{41}$  (Table 1).



SF AMPLIFICATION  
 $Q_m$  (30 - 650 ft)

Figure 35. Median and  $\pm 1 \sigma$  amplification factors computed for San Francisco area surficial geologic unit  $Q_m$  (Table 1).

### LA AMPLIFICATION

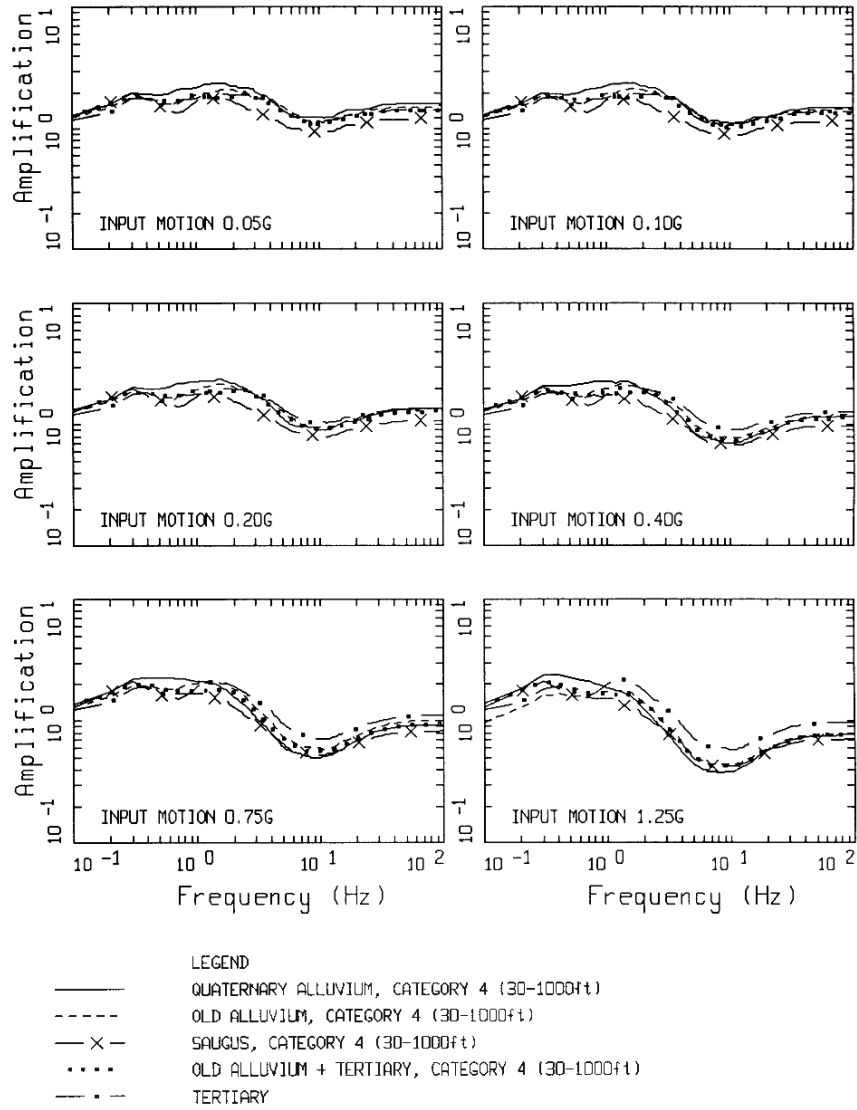
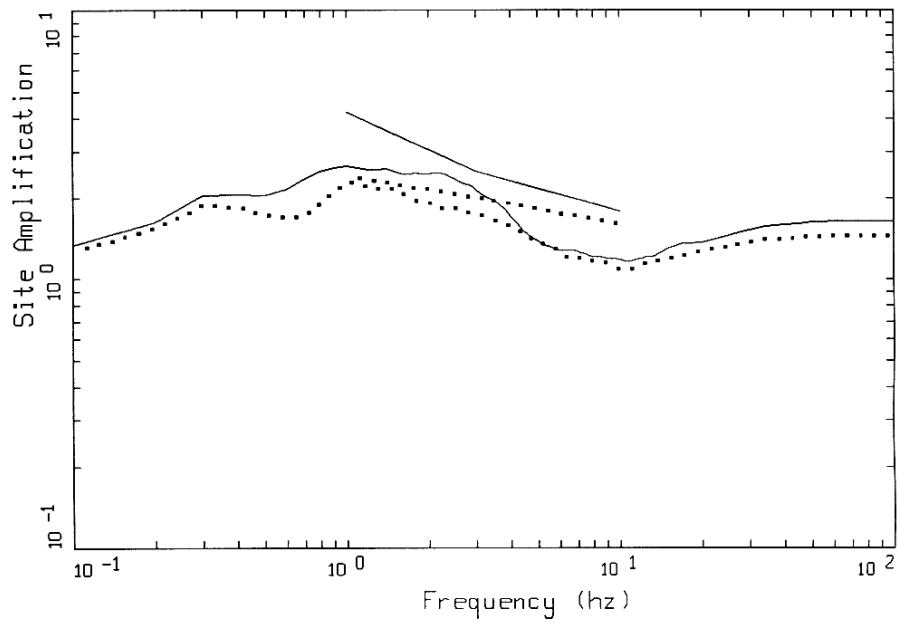


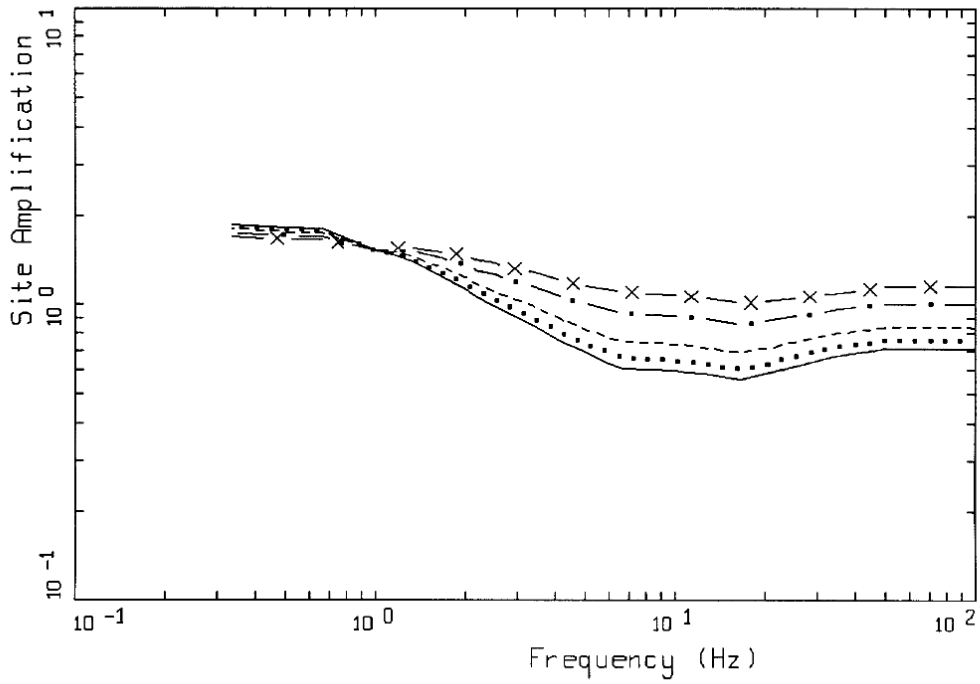
Figure 36. Comparison of median amplification factors computed for units  $Q_p$ ,  $Q_o$ , Saugus ( $T_s$ ),  $T_s$ , and  $Q_o + T_s$  (Table 1) for the depth categories with the widest depth ranges (Table 5).



AMPLIFICATION: 5% DAMPED RESPONSE SPECTRA  
 REFERENCE GRANITE 0.05 G

- LEGEND
- $Q_y$ , 350-650ft (5% Damped Response Spectra, median)
  - ..... QUATERNARY( $Q_o$ )+TERTIARY( $T_s$ ) 350-650ft (5% Damped Response Spectra, median)
  - $Q_y(D)$  (Bonilla et al (1997) Empirical Fourier Amplitude Spectra, average)
  - .....  $Q_o+T_s(C)$  (Bonilla et al (1997) Empirical Fourier Amplitude Spectra, average)

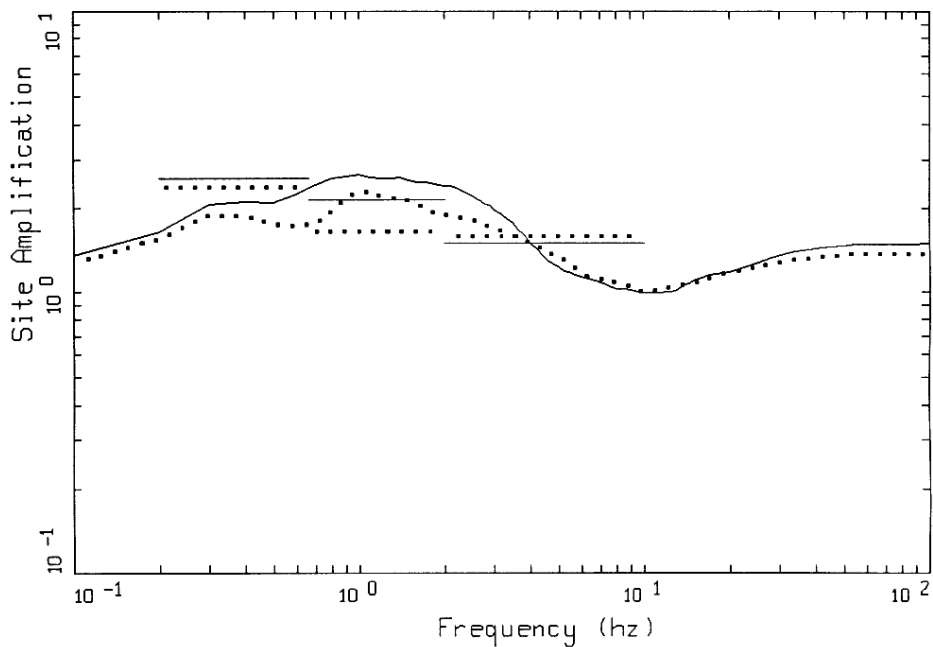
Figure 37. Comparison of median amplification factors (5% damped response spectra) computed for reference Granite outcrop peak acceleration of 0.05g with empirical factors (smoothed Fourier amplitude spectra; Bonilla et al., 1997). Empirical factors are based on small earthquakes.



WNA EMPIRICAL M6.5  
SOIL OVER ROCK

LEGEND	
—	D = 1.0 KM, ROCK PGA = 0.715 g
••••	D = 5.0 KM, ROCK PGA = 0.523 g
----	D = 10.0 KM, ROCK PGA = 0.324 g
—•—	D = 25.0 KM, ROCK PGA = 0.131 g
—x—	D = 50.0 KM, ROCK PGA = 0.061 g

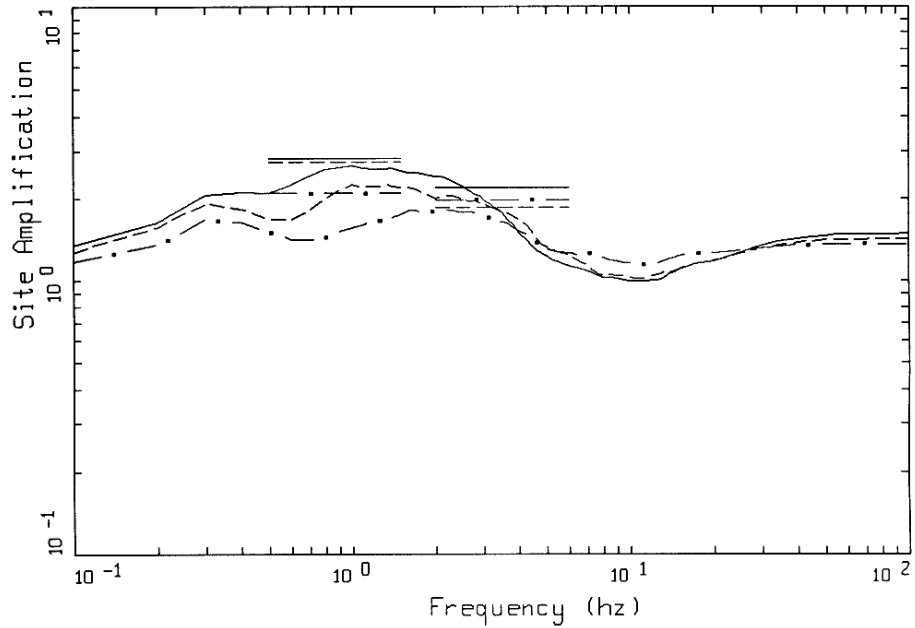
Figure 38. Deep firm to stiff soil (Geomatrix C + D, Table 2) amplification of 5% damped response spectra relative to soft rock (Geomatrix A + B) from an empirical attenuation relation (Abrahamson and Silva, 1997).



AMPLIFICATION: 5% DAMPED RESPONSE SPECTRA  
 REFERENCE GRANITE 0.10 G

- LEGEND
- Qy, Category 3 (350-650 ft)
  - ..... QUATERNARY (Qo) + TERTIARY (Ts), Category 3 (350-650 ft)
  - Qy(D): 2-10 Hz (Borchardt (1996) Empirical 5% Damped Response Spectra, average)
  - Qy(D): 0.67-2.0 Hz
  - Qy(D): 0.2-0.67 Hz
  - ..... Qo+Ts(C): 2.0-10.0 Hz
  - ..... Qo+Ts(C): 0.67-2.0 Hz
  - ..... Qo+Ts(C): 0.2-0.67 Hz

Figure 39. Comparison of median amplification factors (5% damped response spectra) computed for reference Granite outcrop peak acceleration of 0.10g with empirical factors (5% damped response spectra; Borchardt, 1996). Empirical factors are based on recordings of the 1994 M 6.7 Northridge.



AMPLIFICATION: 5% DAMPED RESPONSE SPECTRA  
 REFERENCE GRANITE 0.10 G

- LEGEND
- Qy, Category 3 (350-650ft) (5% Damped Response Spectra, median)
  - Qo, Category 3 (350-650ft) (5% Damped Response Spectra, median)
  - · - Ts (5% Damped Response Spectra, median)
  - Qy(D): 0.5-1.5 Hz (Harmsen (1997): Empirical Fourier Amplitude Spectra, average)
  - Qo(C): 0.5-1.5 Hz
  - · - Ts(C): 0.5 - 1.5 Hz
  - Qy(D): 2.0-6.0 Hz (Harmsen (1997): Empirical Fourier Amplitude Spectra, average)
  - Qo(C): 2.0-6.0 Hz
  - · - Ts(C): 2.0-6.0 Hz

Figure 40. Comparison of median amplification factors (5% damped response spectra) computed for reference Granite outcrop peak acceleration of 0.10g with empirical factors (smoothed Fourier amplitude spectra; Harmsen, 1997). Empirical factors are based on the 1971 San Fernando, 1987 Whittier Narrows, 1991 Sierra Madre, and 1994 Northridge earthquakes.



### LA AMPLIFICATION

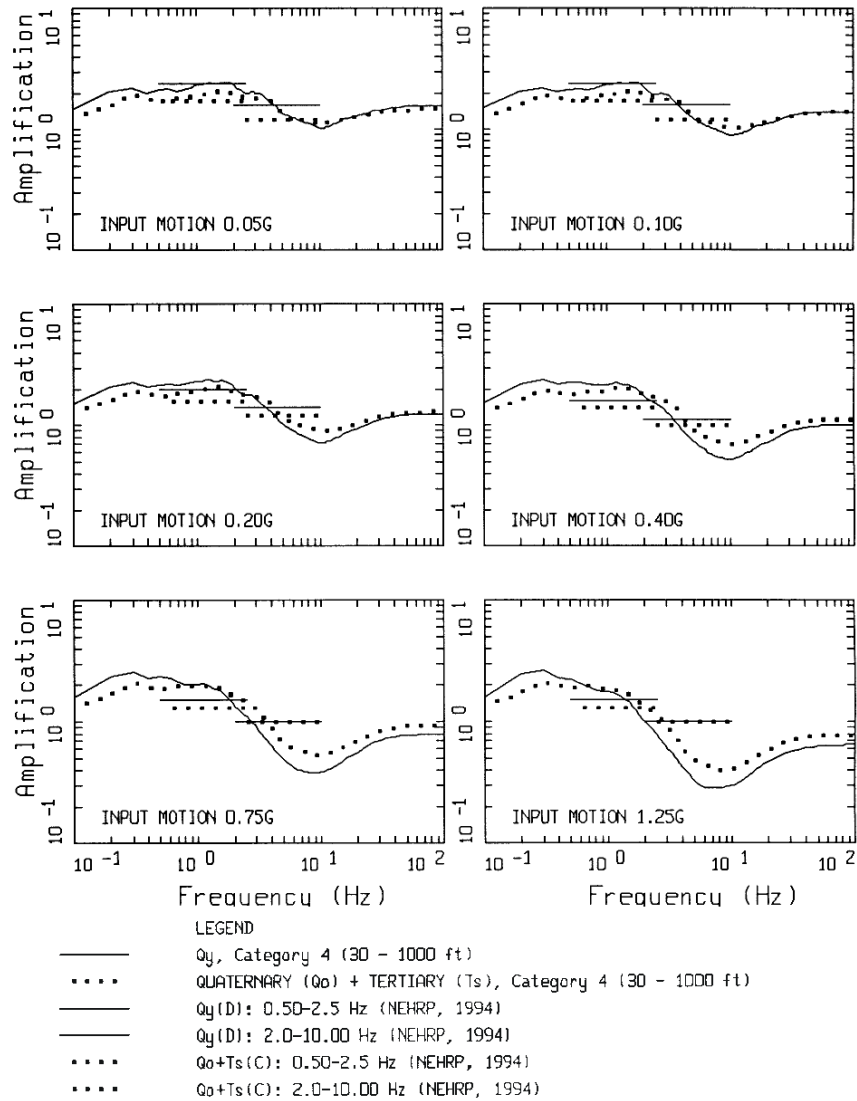
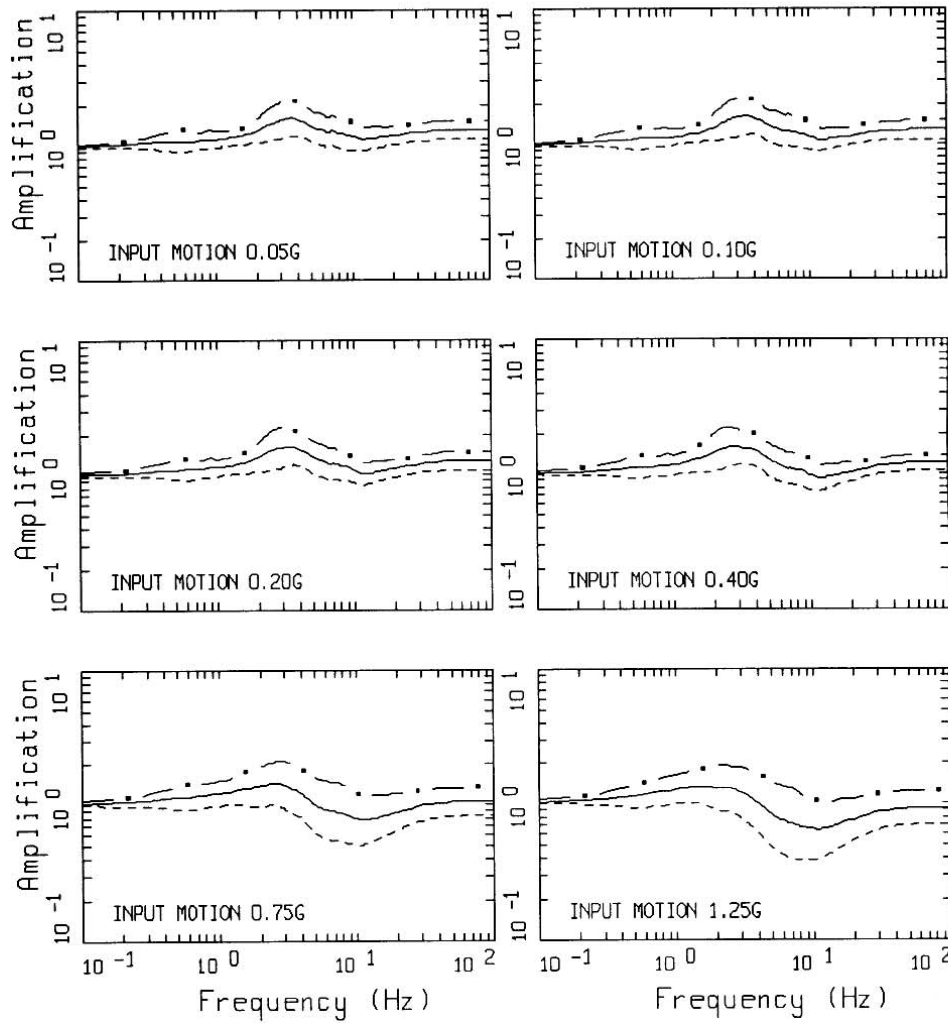
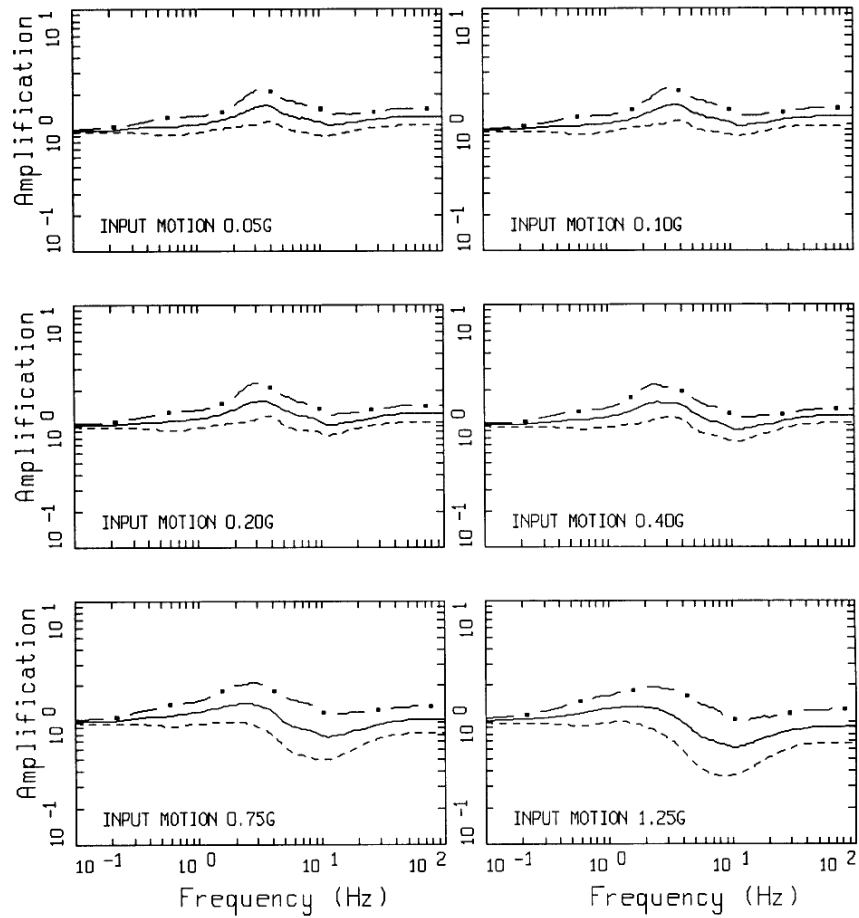


Figure 41. Comparison of median amplification factors with NEHRP provisions.



SF AMPLIFICATION  
 GEOMATRIX CLASS A & B

Figure 42. Amplification factors computed for Geomatrix site categories A and B (Figure 6, Table 2) relative to San Francisco area reference rock outcrop Franciscan.



LA AMPLIFICATION  
 GEOMATRIX CLASS A & B

Figure 43. Amplification factors computed for Geomatrix site categories A and B (Figure 6, Table 2) relative to Los Angeles area reference rock outcrop Granite.