

Development of
Linear-Elastic Amplification Factors
(FAS)
For NEHRP Categories
in CENA

Bob Darragh
Walt Silva

Workshop on Seismic Site Amplification
in Central and Eastern North America

July 21, 2016

PEER, Berkeley, Ca

- Objective
 - Present Crustal Amplification Factors (5% damped spectra) for NEHRP Categories
 - Reference:
NGA-East: Median Ground-Motion Models for the Central and Eastern North American Region (PEER 2015/04)

Assumptions and Issues

–Assumed deep soils and soft-to-firm rock conditions for WNA and CENA reflect generally similar dynamic material properties at low strain levels

Assumptions and Issues

- Relative distribution of material types and ages may be somewhat different between WNA and CENA (e.g. more till, loess and residual (sapprolite) soils in CENA compared to WNA).
- The similarity in deep soil and soft-to-firm rock may imply generally similar overall category specific amplification.

Assumptions and Issues

–Glaciated region outside of basins (e.g. Michigan, Illinois, and Williston) likely have shallow soils sites

Velocity Profiles

NEHRP Class Vs(30m) m/s

A	2032
B	1170
C	560
D	270
E	180

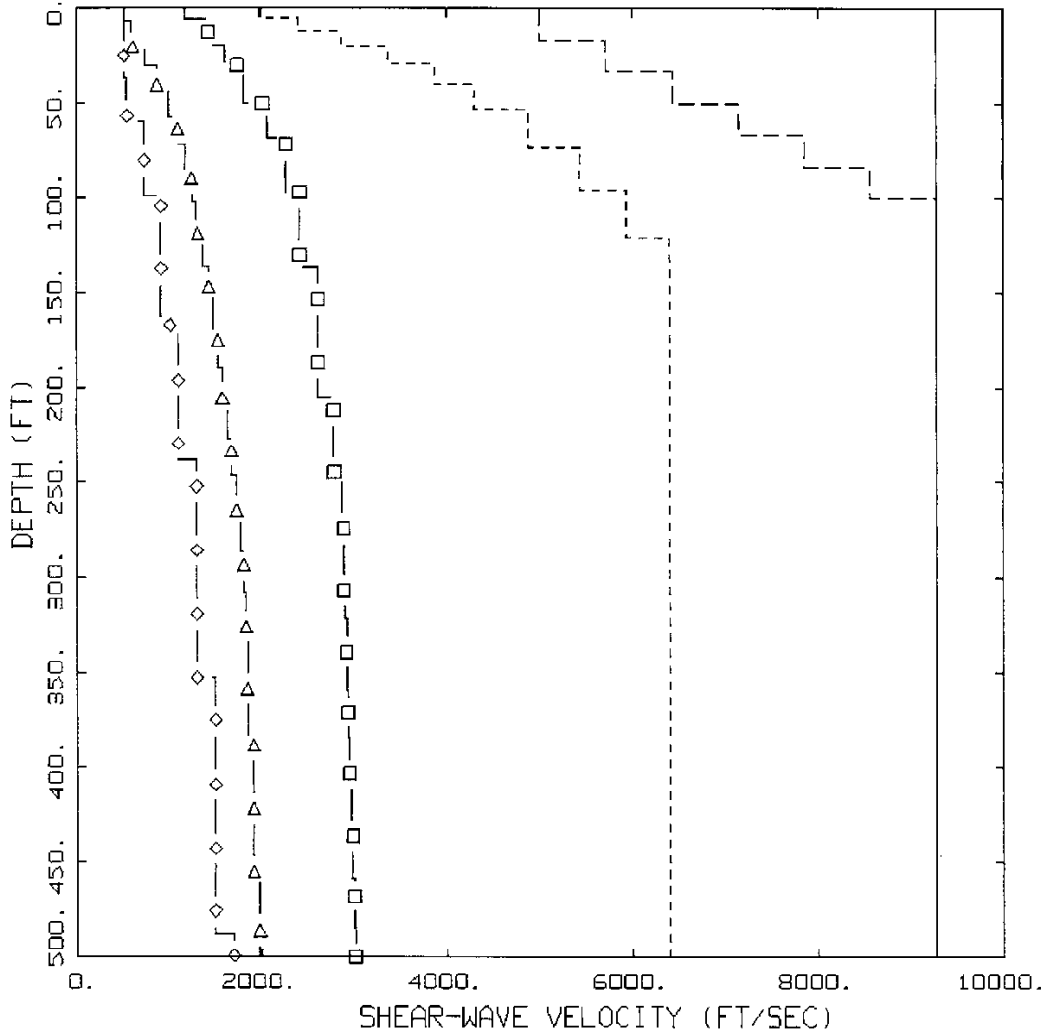
From Kamai et al (2013)

CENA Hard rock

Thickness (km)	Vs (km/s)	Density (g/cm ³)
1.0	3.00	2.52
11.0	3.52	2.71
28.0	3.80	2.78
-----	4.68	3.35

Profiles placed on top of CENA crust

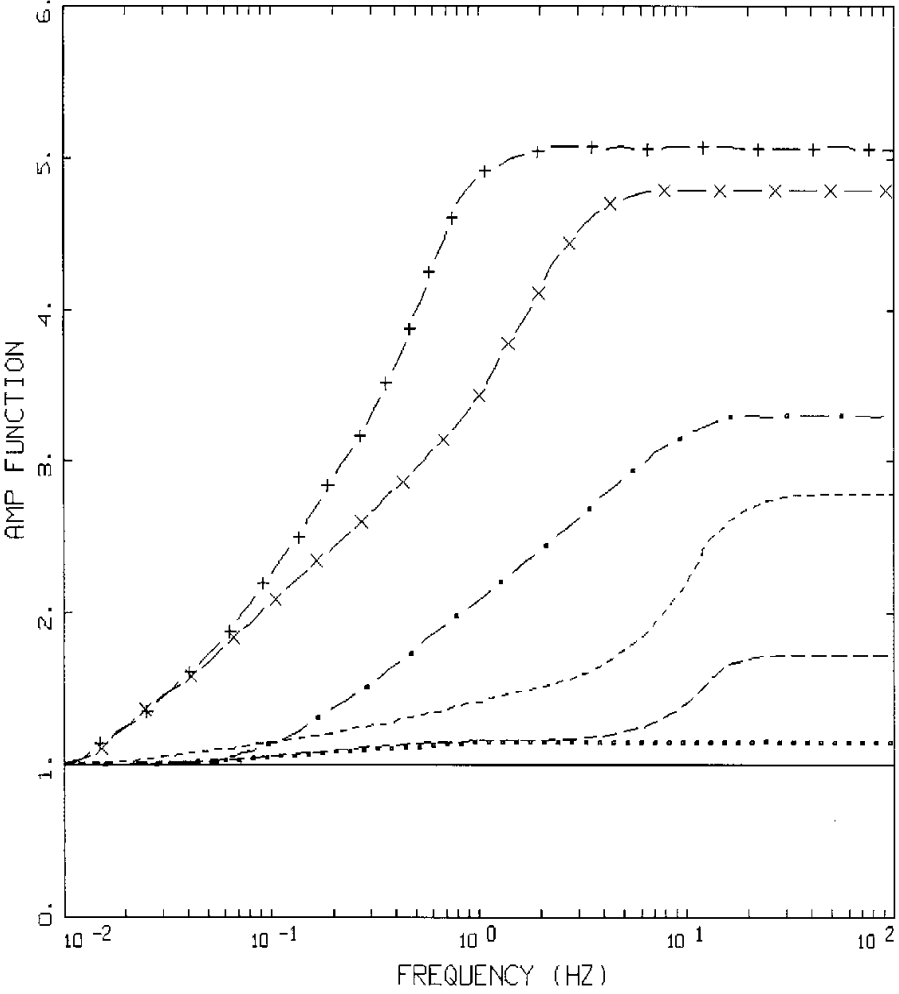
NEHRP category specific shear-wave velocity profiles plotted to 500 ft. NEHRP B profile reaches hard rock at an assumed depth of about 1500 ft, while profiles NEHRP C, D, and E reach hard rock at an assumed depth of about 4000 ft. Depth taken to accommodate lowest frequency of interest (0.1 Hz)



CENA SHEAR WAVE PROFILES

- LEGEND
- 3,000 M/SEC, NEHRP A, HARD ROCK
 - 2,032 M/SEC, NEHRP A
 - 1,170 M/SEC, NEHRP B
 - 560 M/SEC, NEHRP C
 - △— 270 M/SEC, NEHRP D
 - ◇— 180 M/SEC, NEHRP E

Smoothed linear elastic amplification factors (for FAS) developed for NEHRP site categories A, B, C, D, and E



AMPLIFICATION FACTORS

- LEGEND
- 3,000 M/S, NEHRP A, HARD ROCK
 - 2,032 M/S, NEHRP A
 - 1,170 M/S, NEHRP B
 - . - 560 M/S, NEHRP C
 - x - 270 M/S, NEHRP D
 - + - 180 M/S, NEHRP E
 - _____ UNITY

Inversions

- FAS from CENA Regions 1 and 2 events (earthquakes and PIE, FAS from NGA-E)
- Distance to 1000 km
- Simple geometric attenuation assumed
- Only results from Region 2 are shown

CENA regions not used in an inversion due to lack of recordings in NGA-E

- Appalachian: e.g. Piedmont, Blue Ridge residual soils
- Gulf Coast Plane
- Atlantic Coastal Plane

Inversion: Region 2

- 43 earthquakes

$$2.37 \leq \mathbf{M} \leq 5.81$$

- 10 PIE events

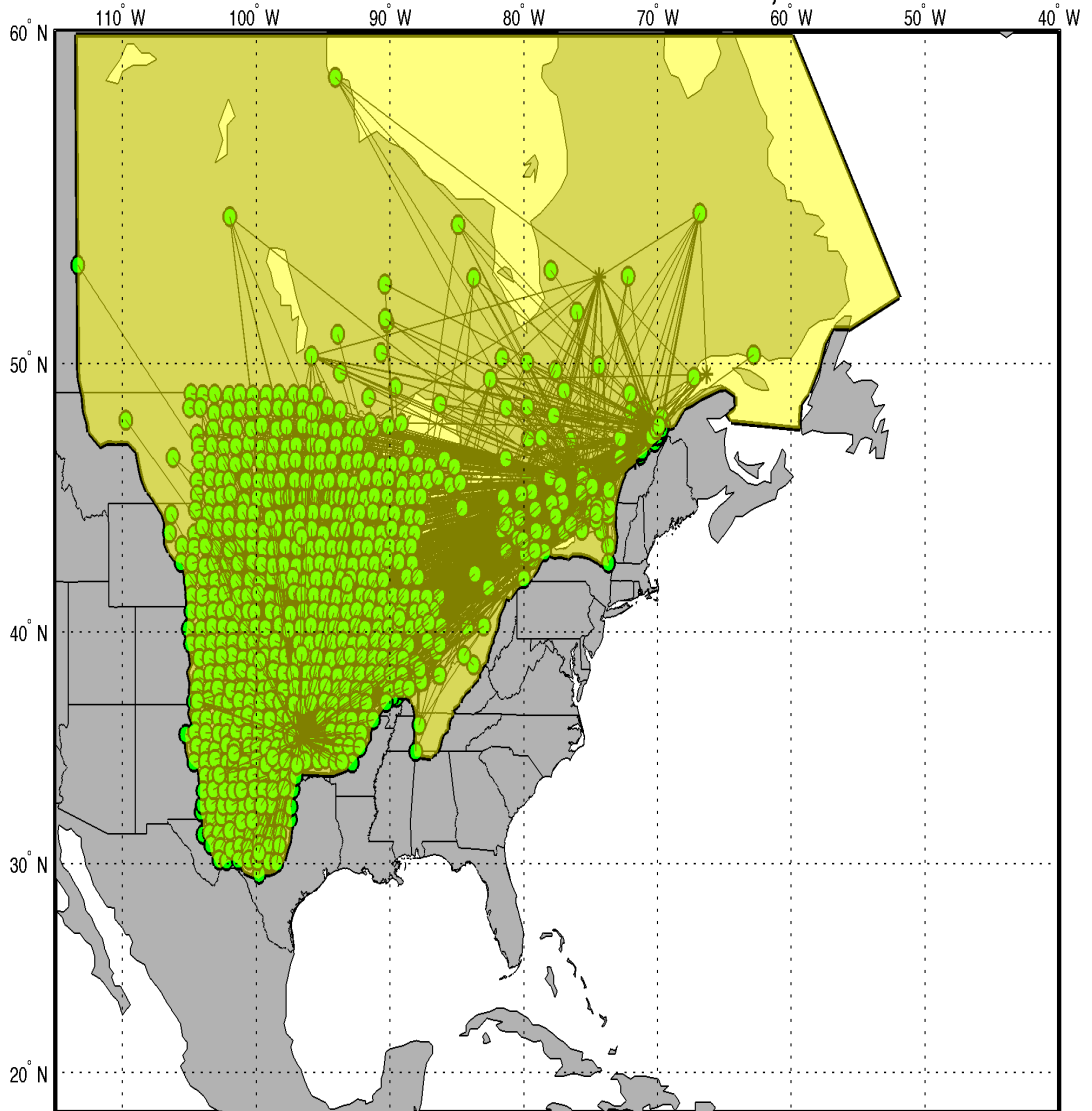
$$3.84 \leq \mathbf{M} \leq 5.68$$

Inversion: Region 2

NEHRP Site Class	Number of Recordings	Unique Sites
-------------------------	-----------------------------	---------------------

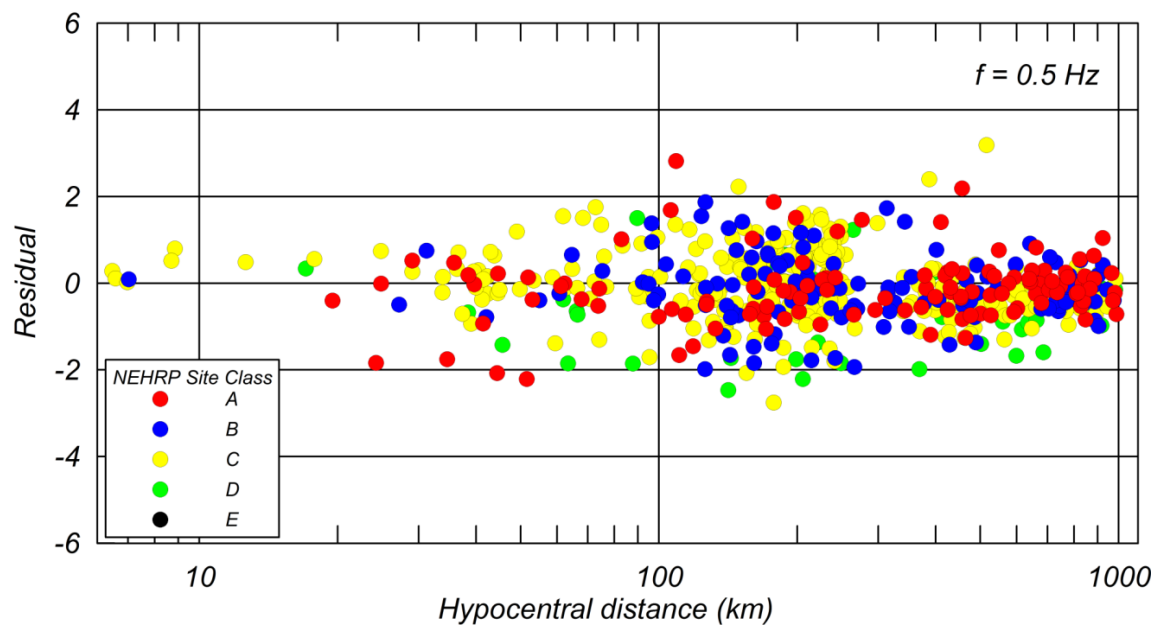
A	351	43
B	248	52
C	441	112
D	85	22
E	6	1

2 : Paths contained within Central US, Canada Ext.



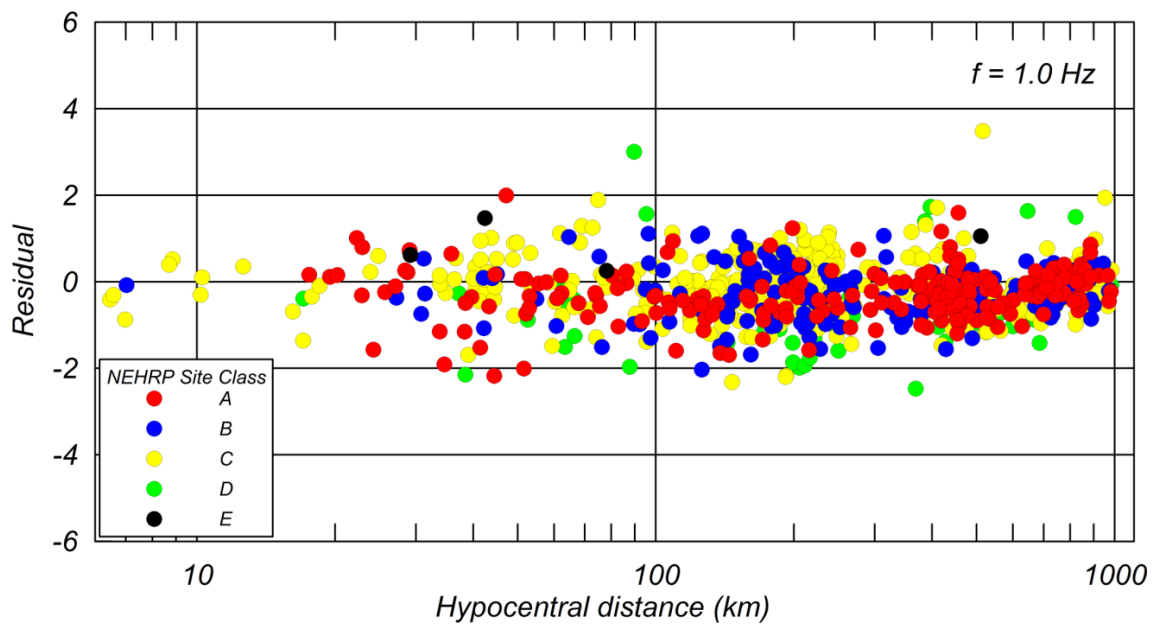
Residuals versus distance for the five NEHRP site

categories: 0.5 Hz



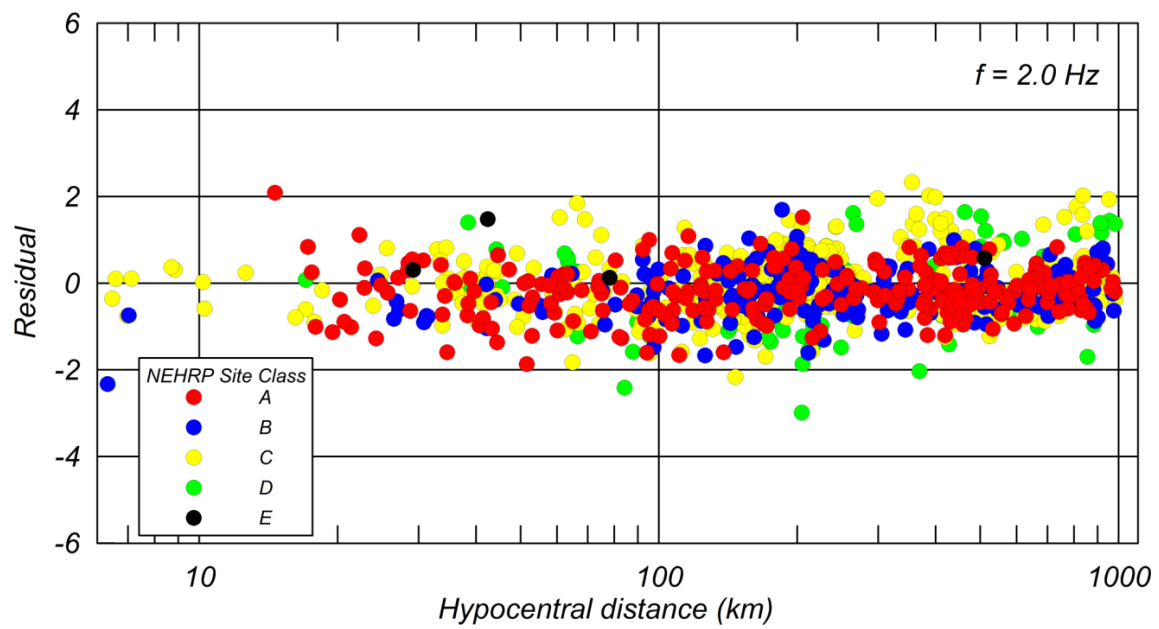
Residuals versus distance for the five NEHRP site

categories: 1.0 Hz



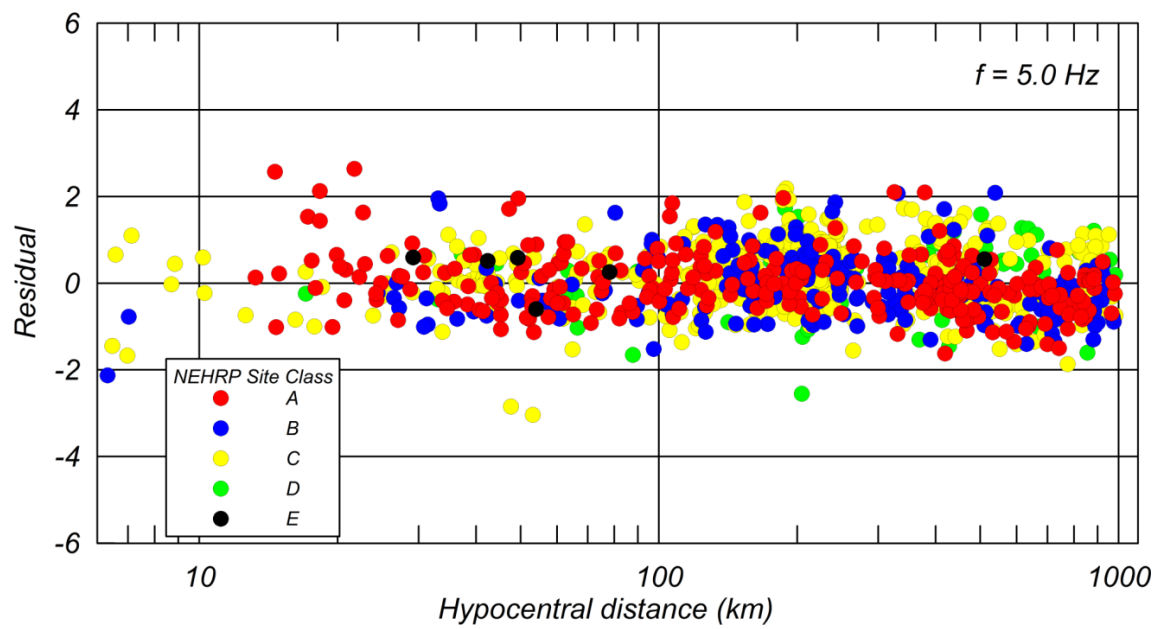
Residuals versus distance for the five NEHRP site

categories: 2.0 Hz

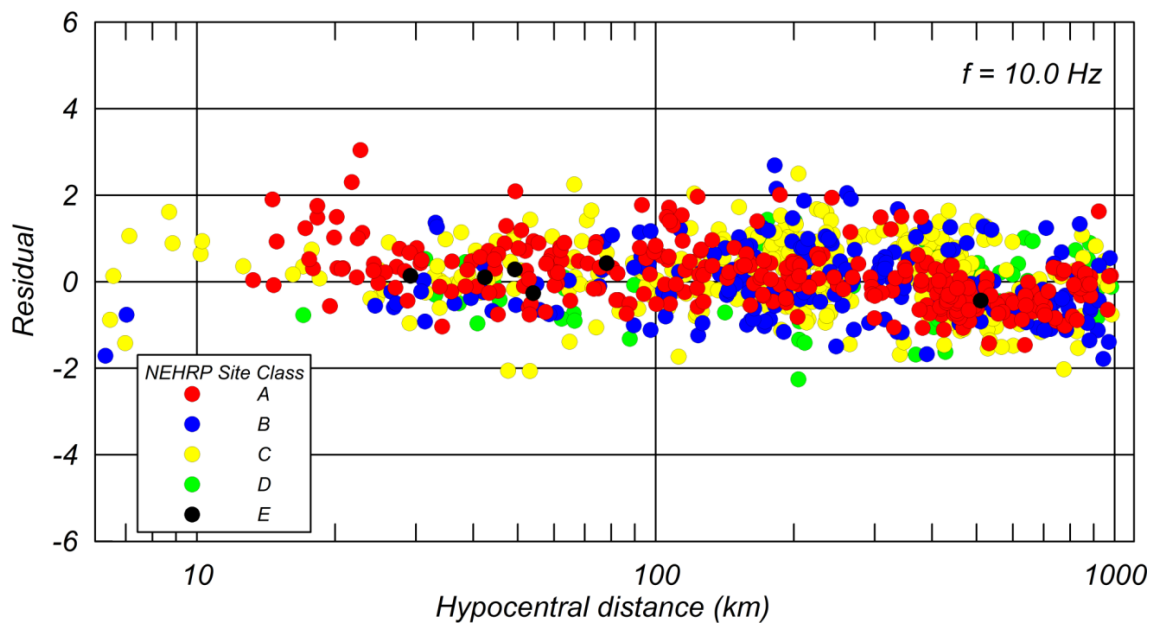


Residuals versus distance for the five NEHRP site

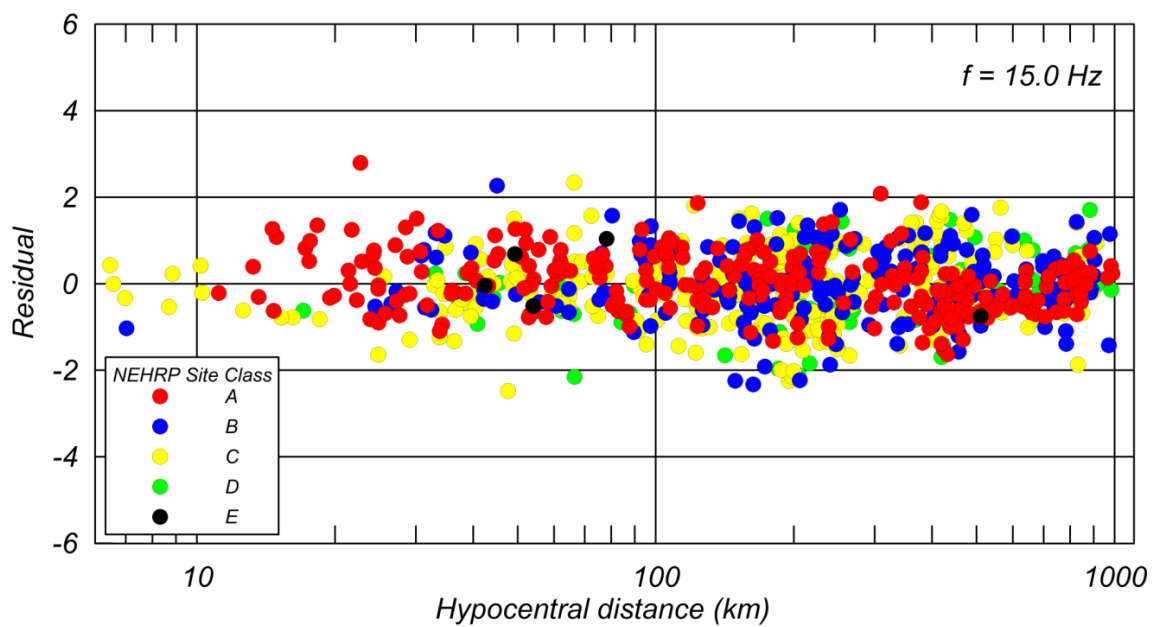
categories: 5.0 Hz



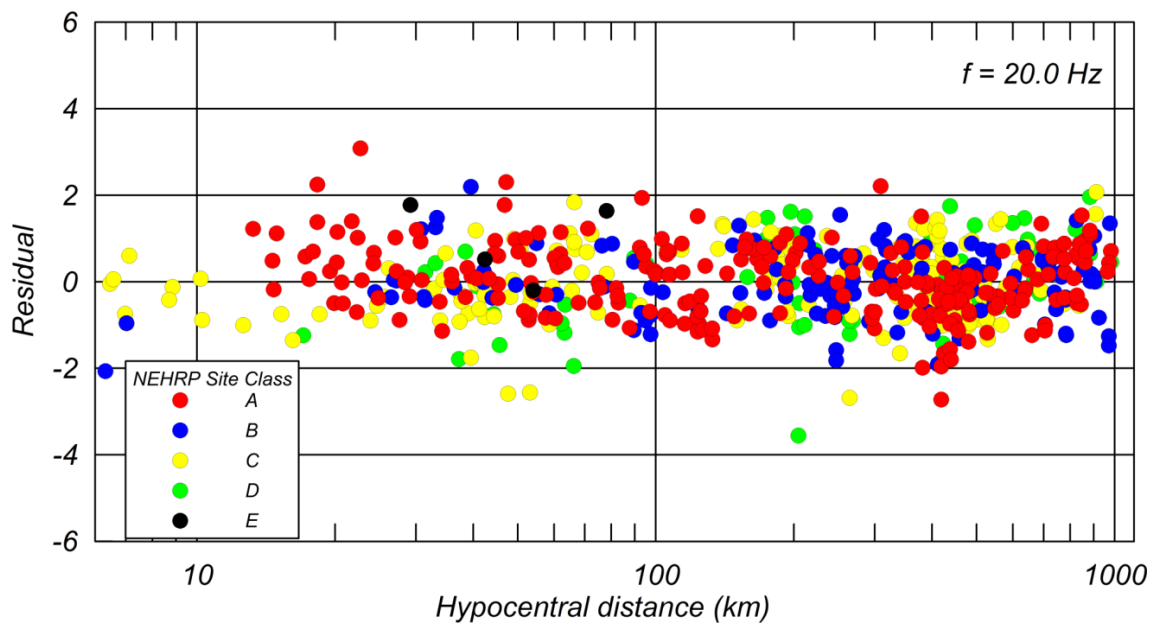
Residuals versus distance for the five NEHRP site categories: 10.0 Hz



Residuals versus distance for the five NEHRP site categories: 15.0 Hz



Residuals versus distance for the five NEHRP site categories: 20.0 Hz.



Residuals from Region 2 Inversion

Overall the distribution of residuals are acceptable across NEHRP site class, frequency and distance.

The distribution of residuals spanning the frequency range from 0.5 to 20 Hz suggest that the NEHRP amplification factors may reflect little bias across frequency

Uncertainty in $V_s(30m)$ assignments may be contributing to variability in residuals

Extension to
Amplification Factors
from Additional Profiles
and Strain Compatible Properties
in CENA

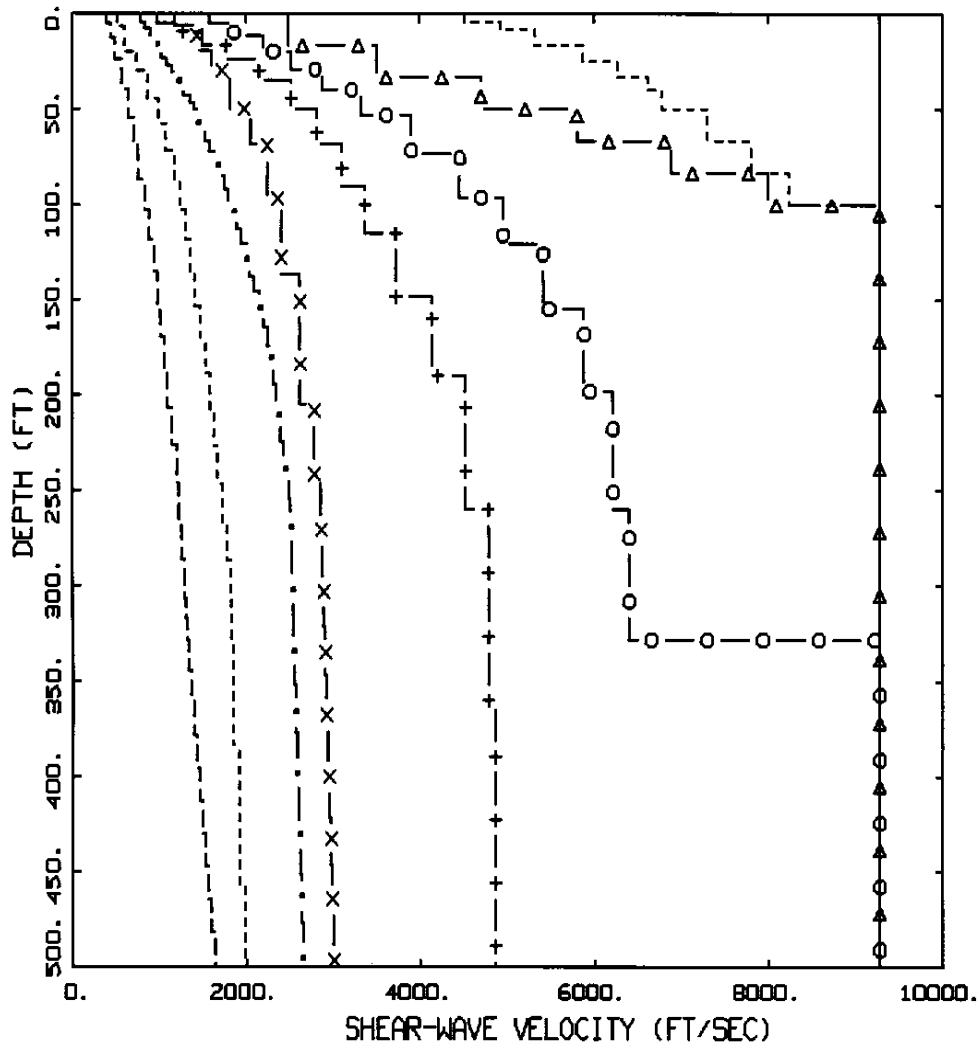
Amplification Factors For CENA

- Strain Compatible Properties
- Generic CENA Soil and Rock Sites
- 8 Categories (6 soil, 2 rock)
 - 180 to 2,032m/s
- 7 Depth Bins
 - 25 to 2,000 ft
 - 10 sec, extend to 4,000 ft
- QA: Compare with amplification factors for CENA region/site-specific profiles

Table 1 Profile Categories	
Categories	$\overline{V_s}$ (30m)
	180
	270
	400
	560
	740
	900
	1,364
	2,032
Depth to Very Hard Rock (ft) for Each Category	
	25 ± 10
	50 ± 20
	100 ± 40
	200 ± 80
	500 ± 200
	1,000 ± 400
	2,000 ± 800

Hard rock crustal model (EPRI, 1993)

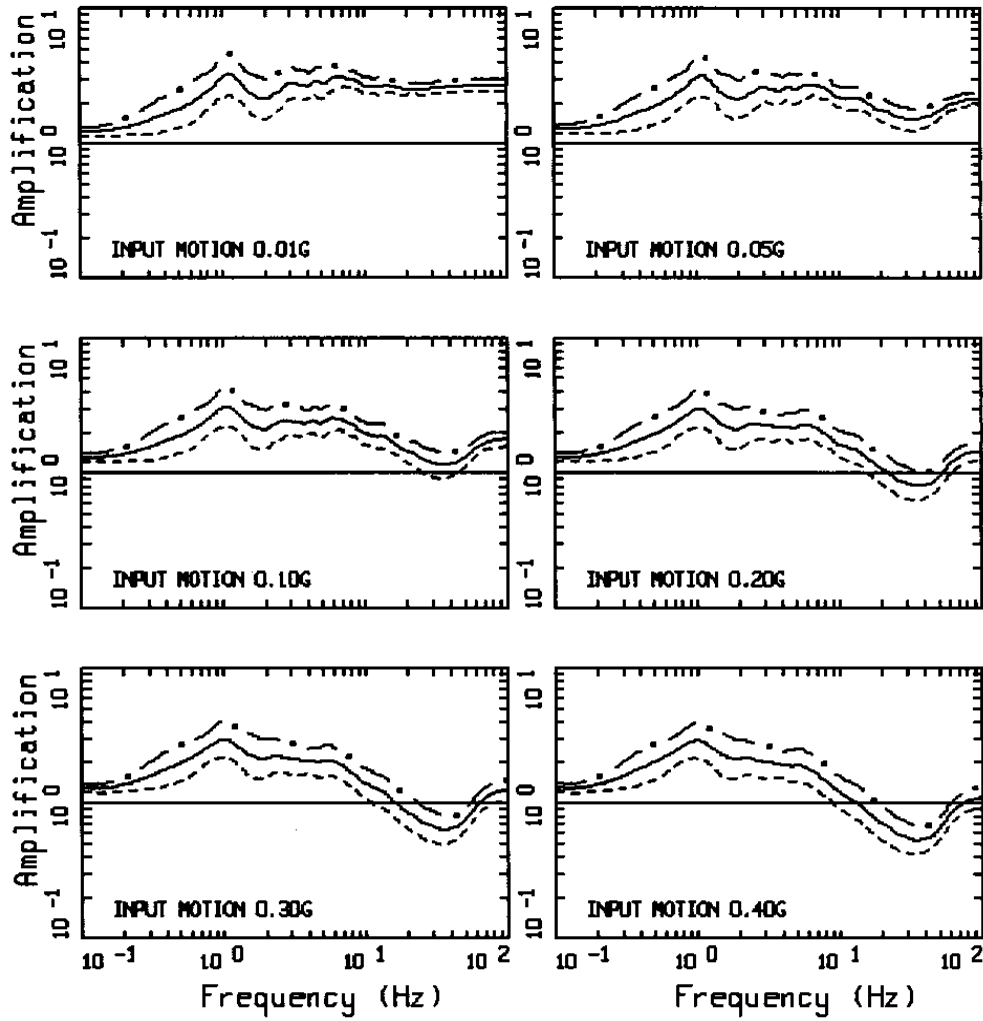
th (km)	Vs (km/sec)	Vp (km/sec)	p (cgs)
1	2.83	4.90	2.52
11	3.52	6.10	2.71
28	3.75	6.50	2.78
	4.62	8.00	3.35



CENA SHEAR WAVE PROFILES

- LEGEND
- S-WAVE: 180 M/SEC
 - S-WAVE: 270 M/SEC
 - .-.- S-WAVE: 400 M/SEC
 - X- S-WAVE: 560 M/SEC
 - +- S-WAVE: 740 M/SEC
 - O- S-WAVE: 900 M/SEC
 - Δ- S-WAVE: 1364 M/SEC (SOFT ROCK)
 - S-WAVE: 2032 M/SEC (FIRM ROCK)
 - S-WAVE: 2830 M/SEC (HARD ROCK)

CENA Amplification Factors for
NEHRP Category C
($V_s(30m) = 400 \text{ m/s}$)



AMPLIFICATION(H), 400 M/SEC, 500 FT OVER HARD ROCK
 EPRI CURVES: PAGE 1 OF 2

Thickness and Amplification Factors

7 Depths over Hard Rock
for

$$V_s (30 \text{ m}) = 270 \text{ m/s}$$

NEHRP D

25 ft

50 ft

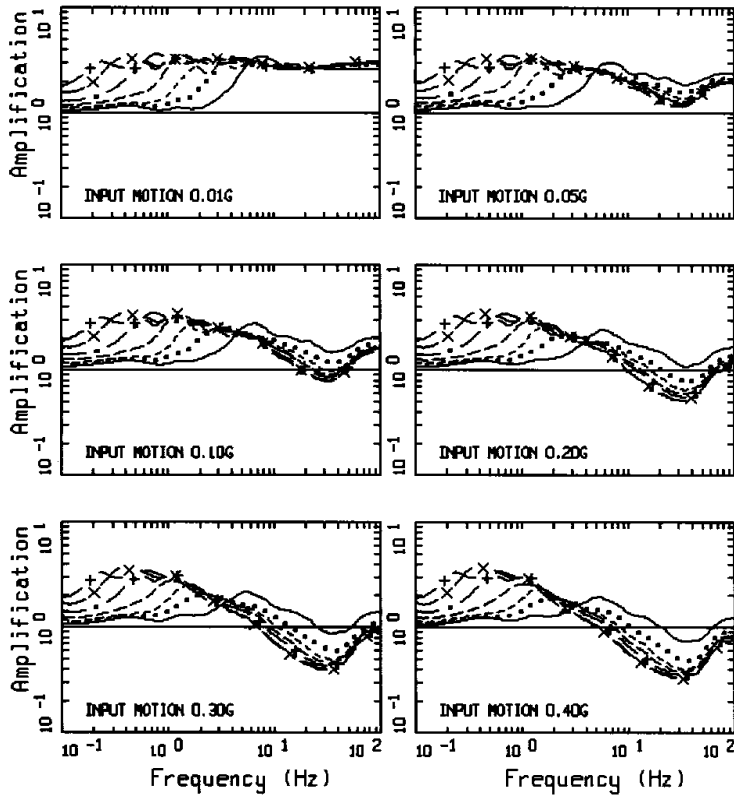
100 ft

200 ft

500 ft

1000 ft

2000 ft



AMPLIFICATION(H), 270 M/SEC, 7 DEPTHS OVER HARD ROCK
 EPRI CURVES: PAGE 1 OF 2

- LEGEND
- 25 FT: 50TH PERCENTILE
 - 50 FT: 50TH PERCENTILE
 - 100 FT: 50TH PERCENTILE
 - 200 FT: 50TH PERCENTILE
 - - - 500 FT: 50TH PERCENTILE
 - - X - 1000 FT: 50TH PERCENTILE
 - - + - 2000 FT: 50TH PERCENTILE

Thickness and Amplification Factors

3 Depths over Hard Rock
for

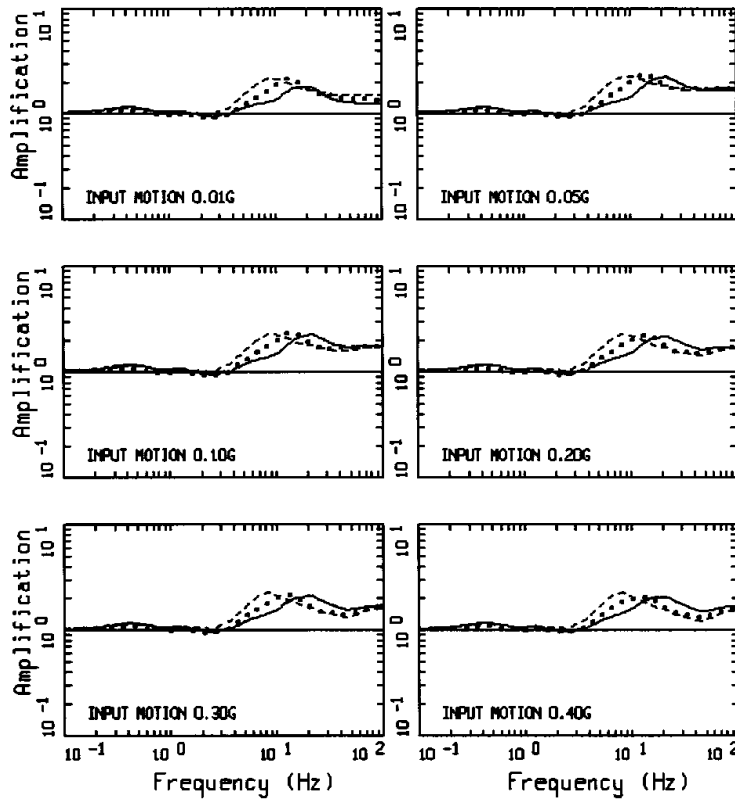
$$V_s (30 \text{ m}) = 900 \text{ m/s}$$

NEHRP B

25 ft

50 ft

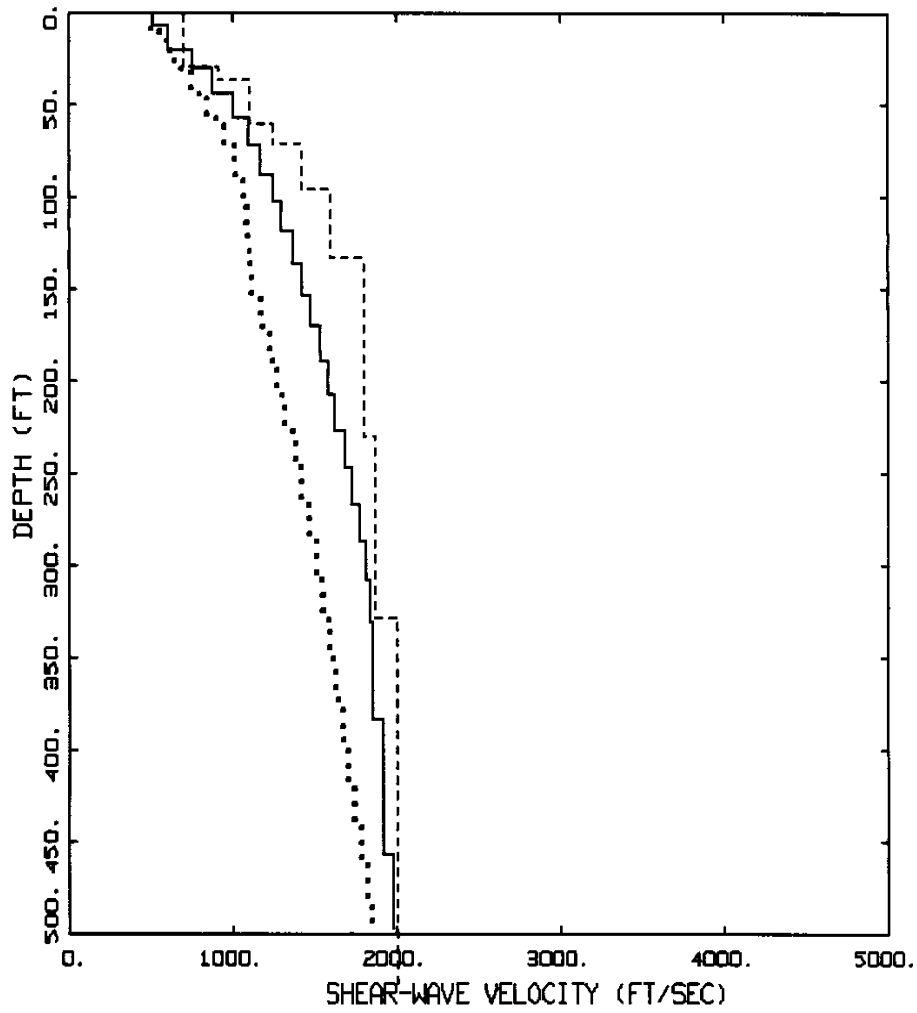
100 ft



AMPLIFICATION(H), 900 M/SEC, 7 DEPTHS OVER HARD ROCK
 EPRI CURVES: PAGE 1 OF 2

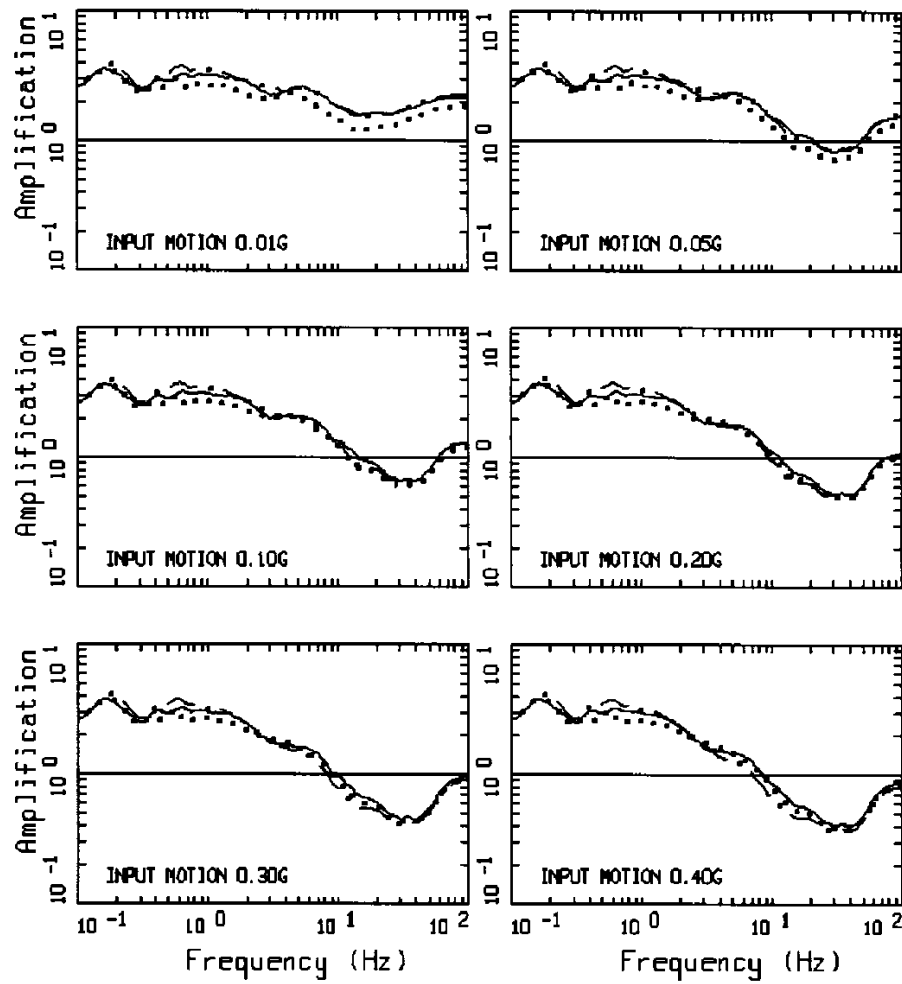
- LEGEND
- 25 FT: 50TH PERCENTILE
 - 50 FT: 50TH PERCENTILE
 - 100 FT: 50TH PERCENTILE
 - 200 FT: 50TH PERCENTILE
 - · - 500 FT: 50TH PERCENTILE
 - × - 1000 FT: 50TH PERCENTILE
 - + - 2000 FT: 50TH PERCENTILE

Amplification Factors
for
Mississippi Embayment Profiles



CENA SHEAR WAVE PROFILES
NEW MADRID

- LEGEND
- S-WAVE: 270 M/SEC
 - S-WAVE: LOWLANDS
 - - - S-WAVE: UPLANDS



AMPLIFICATION

PAGE 1 OF 2

LEGEND

- M = 6.00, 1 CORNER, NGA DEEP FIRM SOIL, VS(30M) = 270 M/SEC
- - - M = 6.00, 1 CORNER, LOWLANDS, VS(30M) = 238 M/SEC
- M = 6.00, 1 CORNER, UPLANDS, VS(30M) = 300 M/SEC, M1P2
- UNITY LINE