NEHRP SITE CLASS (V_S(30m))

AMPLIFICATION FACTORS FROM

SITE RESPONSE SIMULATIONS

by

Pacific Engineering and Analysis

January 2005

Shear-Wave Velocity Profiles

For site response analyses, generic shear-wave velocity profiles were developed from a suite of surficial geology based empirical profiles developed for the Los Angeles and San Francisco Bay regions (Silva et al., 1999). The geologic units and corresponding average shear-wave velocities over the top 30m are listed in Table 1. To develop a suite of profiles for site response analyses over a range in $\overline{V_S}$ (30m) values, geologic unit profiles were selected that were closest to the desired $\overline{V_S}$ (30m) values. The entire soil profile was then scaled to a depth where rock (defined as 1 km/sec material) was encountered. Table 2 lists the suite of $\overline{V_S}$ (30m) values and corresponding NEHRP Categories and Figure 1 shows the profiles plotted to a depth of 500 ft. NEHRP Category A profile, with $\overline{V_S}$ (30m) of 2,830 m/sec was taken as the EPRI (1993) Midcontinent model, appropriate for CEUS hard rock sites. This profile was given a kappa value of 0.006 sec (EPRI, 1993), with the remaining profiles all having a low strain kappa values of 0.04 sec, appropriate for soil and soft rock sites (Silva et al., 1997). Reference site conditions are taken as NEHRP Category B, with a $\overline{V_S}$ (30m) value of 1,130 m/sec, the midpoint of NEHRP Category B $\overline{V_S}$ (30m) range (Table 2).

G/Gmax and Hysteretic Damping Curves

Five sets of G/Gmax and hysteretic damping curves are used: generic rock (NEHRP B), two for cohesionless soils (NEHRP C and D), and two for cohesive soils (NEHRP D and E). The rock curves (Figure 2) are based on point-source modeling of the rock site empirical attenuation relation of Abrahamson and Silva (1997) for a range in magnitudes and distances using a generic rock profile (Silva et al., 1997).

For the geologic units which are considered cohesionless soils (QTs, Q_{al}) in the San Francisco Bay area (gravels, sands, and low PI clays) in terms of high-strain dynamic material properties, the EPRI (1993) G/Gmax and hysteretic damping curves (Figure 3) have recently been validated at 48 San Francisco Bay area cohesionless soil sites through modeling strong ground motions from the Coyote Lake, Morgan Hill, and Loma Prieta earthquakes (Silva et al., 1997). These

curves were developed for generic applications to cohesionless soils in the general range of gravelly sands to low plasticity silts or sandy clays. For application to Quanternary/Tertiary rocks (QT_S; NEHRP Category C), the implied assumption is that these sites behave more like a stiff soil (gravely sand) than rock. Not an unreasonable assumption considering a surface velocity of about 800 ft/sec.

For the Bay Mud (Q_m) category, generic sections of Fill (15 ft), young Bay Mud (50 ft) and old Bay Clay (30 ft) over Quaternary Alluvium (Q_{al}) are assumed. These generic zones are based on an examination of several CALTRANS boreholes located near highway bridges (Cliff Roblee, personal communication) and are used only to assign G/Gmax and hysteretic damping curves. For the Fill material and the Alluvium, EPRI (1993) curves are used. For the young Bay Muds and Old Bay Clay, the Vucetic and Dobry (1991) cohesive soil curves for a *PI* of 30%, an average value for these cohesive soils, are used (Figure 4).

To cover the potential range in nonlinearity at soft soil sites, a generic Imperial Valley profile is considered. This profile has a $\overline{V_S}$ (30m) value of 190m/sec (Table 2) and is based on measured shear-wave velocities across the El Centro Array in Imperial Valley, California. Based on limited laboratory dynamic testing (Turner and Stokoe, 1982) and recordings of the 1979, **M** 6.5 Imperial Valley earthquake (Silva et al., 1997), these soils appear to behave much more linearly than the soft soils along the margins of San Francisco Bay and Mendocino, California (Silva et al., 1997). Although the Imperial Valley soils contain clays, typical PI are less than 30% and the Vucetic and Doby G/Gmax and hysteretic damping curves appear to show too much nonlinearity to be consistent with the high peak accelerations recorded, about 0.5g. As a result, a suite of G/Gmax and hysteretic damping curves was developed for these soils based on the Turner and Stokoe (1982) testing results and modeling of the motions (Silva et al., 1997). The curves are shown in Figure 5 and are quite linear at high strain. Since neither the laboratory testing nor the recorded motions resulted in strains exceeding about 0.1%, the curves are unconstrained at larger strains and were linearly extrapolated. As a result the amplification factors for expected NEHRP Category B peak accelerations exceeding about 0.5g are likely conservative.

For the geologic units which are considered cohesionless soils in the Los Angeles area (QT_S, Q_0, Q_y, Saugus), recent strong ground motion analyses for about 80 sites which recorded the 1994 Northridge earthquake found the EPRI G/Gmax and hysteretic damping curves showed too much nonlinearity (Silva et al., 1997). As a result, a revised set of G/Gmax and hysteretic damping curves were developed for Peninsular Range (BNL) cohesionless soils and are shown in Figure 6. Both sets of cohesionless soil curves are used for NEHRP Categories BC, C, and D*.

Note, eight suites of plots are included. The first set (AMP1) shows NEHRP BC, C, D and E verses NEHRP B spectra while the second set (AMP2) shows amplification verses NEHRP B spectra. Depths are mean depths to a steep (rock) velocity gradient with an initial shear-wave velocity of 1 km/sec. The 30 to 1,000 ft depth category is the depth randomization range (mean depth 515 ft). For the other depth bins, depth randomization is generally about $\pm$ 50% of the mean depth.

Reference:

Silva, W. J.,S. Li, B. Darragh, and N. Gregor (1999). "Surface geology based strong motion amplification factors for the San Francisco Bay and Los Angeles Areas."A PEARL report to PG&E/CEC/Caltrans, Award No. SA2120-59652.

Silva, W.J., N. Abrahamson, G. Toro and C. Costantino. (1997). "Description and validation of the stochastic ground motion model." Report Submitted to Brookhaven National Laboratory, Associated Universities, Inc. Upton, New York 11973, Contract No. 770573.

Turner, E. and K. H. Stokoe II (1982). “Static and dynamic properties of clayey soils subjected to 1979 Imperial Valley earthquake.” A report on research sponsored by United States Geological Survey Branch of Engineering Geology. *Geotechnical Engineering Report GR82-26.*

*For a more complete description please see the NEHRP report 98-HQ-GR-1010 on our web site (www.pacificengineering.org).

Table 1 **SURFACE GEOLOGY BASED PROFILES AND SITE CLASSES**			
San Francisco Bay Area			
Geology	Average Velocity over 30m	Site Classes NEHRP	Number of Profiles
K_{jf} (Franciscan)	771.44 m/s	B	30
TM_{ZS} (Tertiary Bedrock)	506.13 m/s	C	18
QT_S(Quaternary/Tertiary)	466.12 m/s	C	9
Q_{oa} (older alluvium)	353.44 m/s	D	16
Q_{al} (Quaternary alluvium)	296.49 m/s	D	37
Q_{oa} + Q_{al}	312.15 m/s	D	53
Q_m (Bay mud)	187.87 m/s	D	60
			170
Los Angeles Area			
Geology	Average Velocity over 30m	Site Classes NEHRP	Number of Profiles
M_{xb} (Granite)	843.78 m/s	B	8
T_S (Saugus)	576.81 m/s	C	4
T_S (Tertiary)	436.39 m/s	C	43
Q_o (Older alluvium)	391.24 m/s	C	124
QT_S (Q_o + T_S)	508.61 m/s	C	171
Q_y (Quaternary alluvium)	317.68 m/s	D	219
			398

Table 2

Suite of $\overline{V_S}$ (30m) Values

NEHRP Category	$\overline{V_S}$ (30m) (m/sec)
A	2,830
B	1,130
B	900
BC	750
C	564
C	400
D	270
D	190
E	165

NEHRP Categories	
Category	$\overline{V_S}$ (30m) (m/sec)
A	> 1,500
B	760 – 1,500
C	360 – 760
D	180 – 360
E	< 180

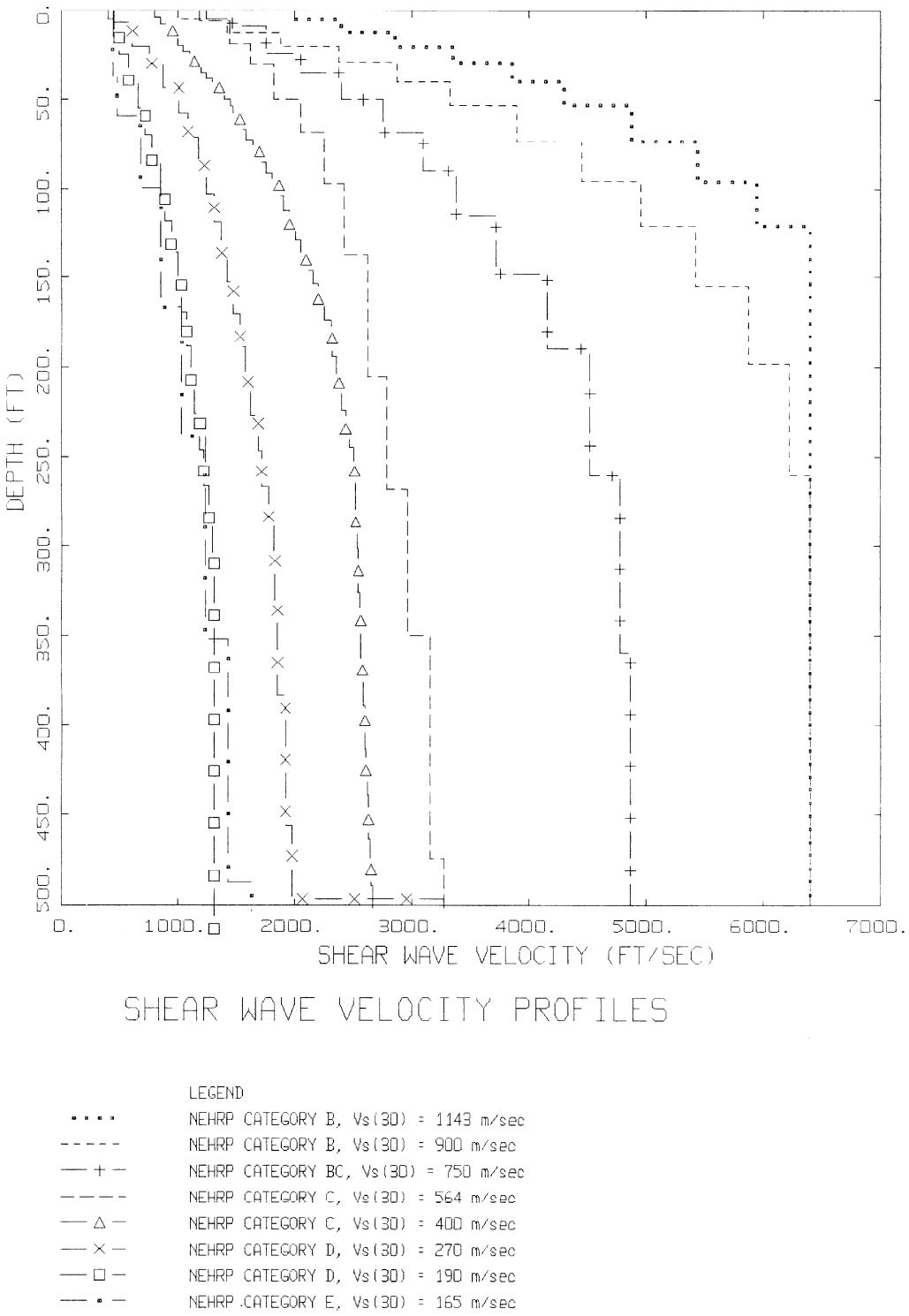


Figure 1. Shear-wave velocity profiles and corresponding average velocities to 30m (100 ft).

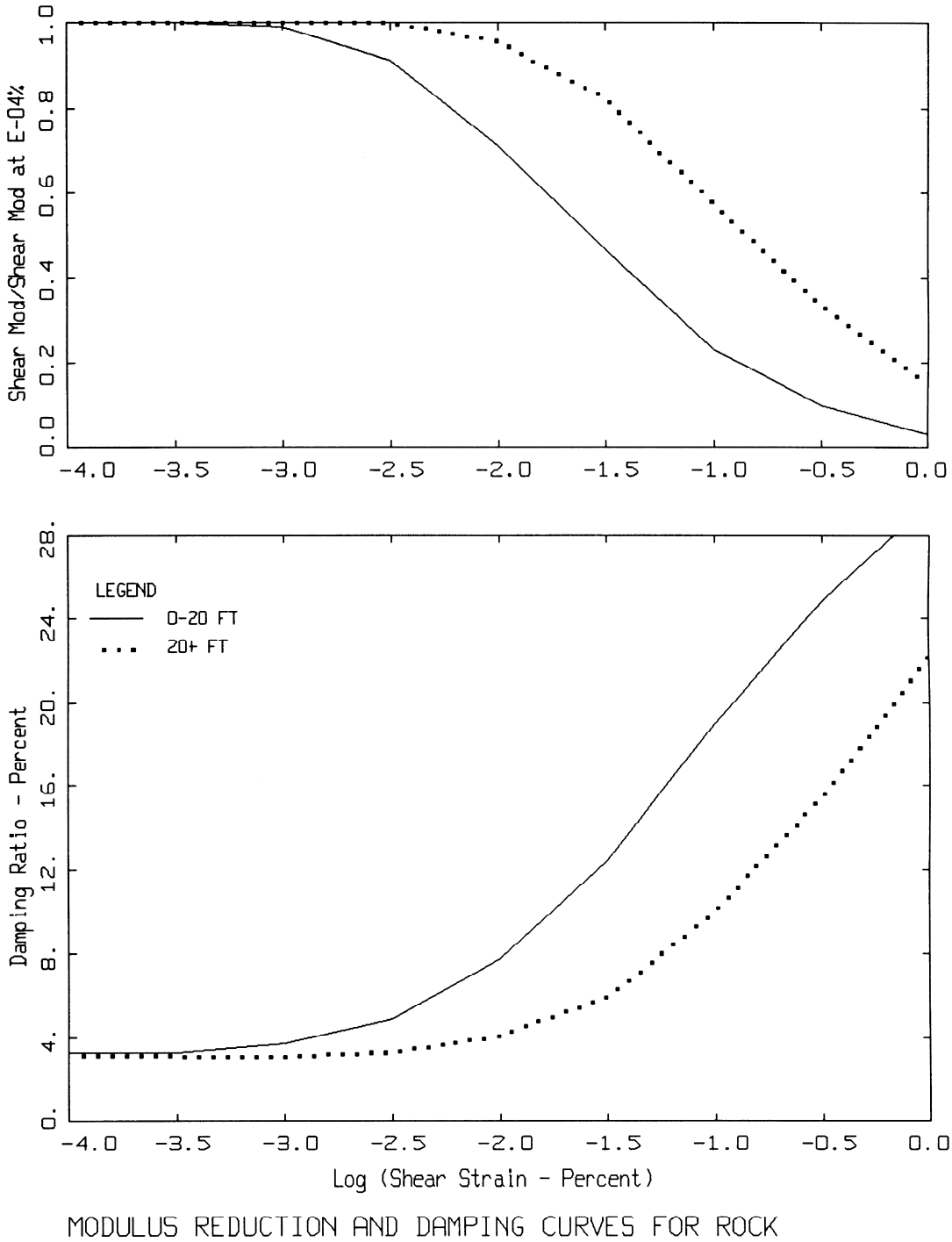
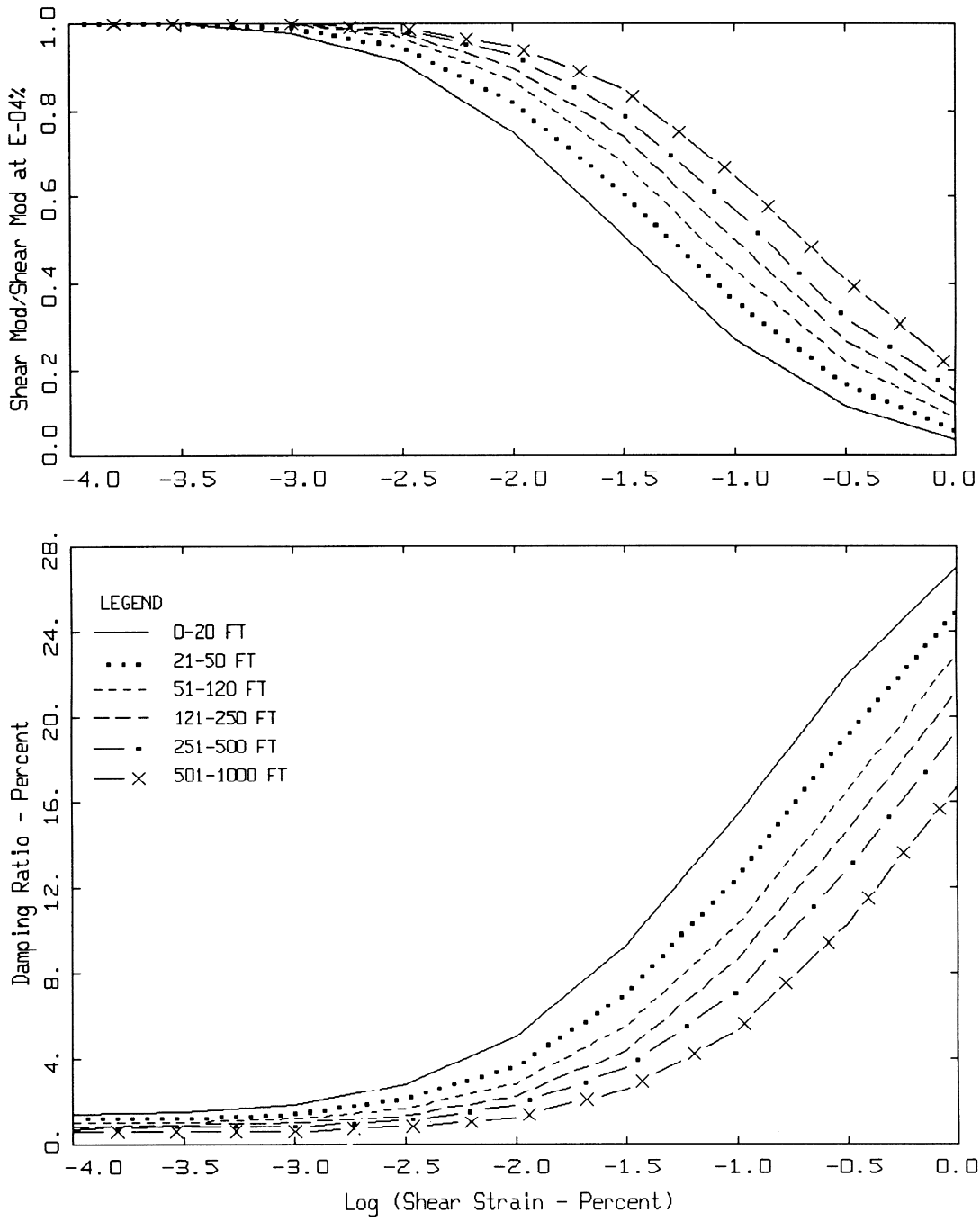


Figure 2. Generic G/Gmax and hysteretic damping curves for rock site conditions.



MODULUS REDUCTION AND DAMPING CURVES FOR COHESIONLESS SOILS

Figure 3. Generic G/Gmax and hysteretic damping curves for North Coast cohesionless soil site conditions (EPRI, 1993).

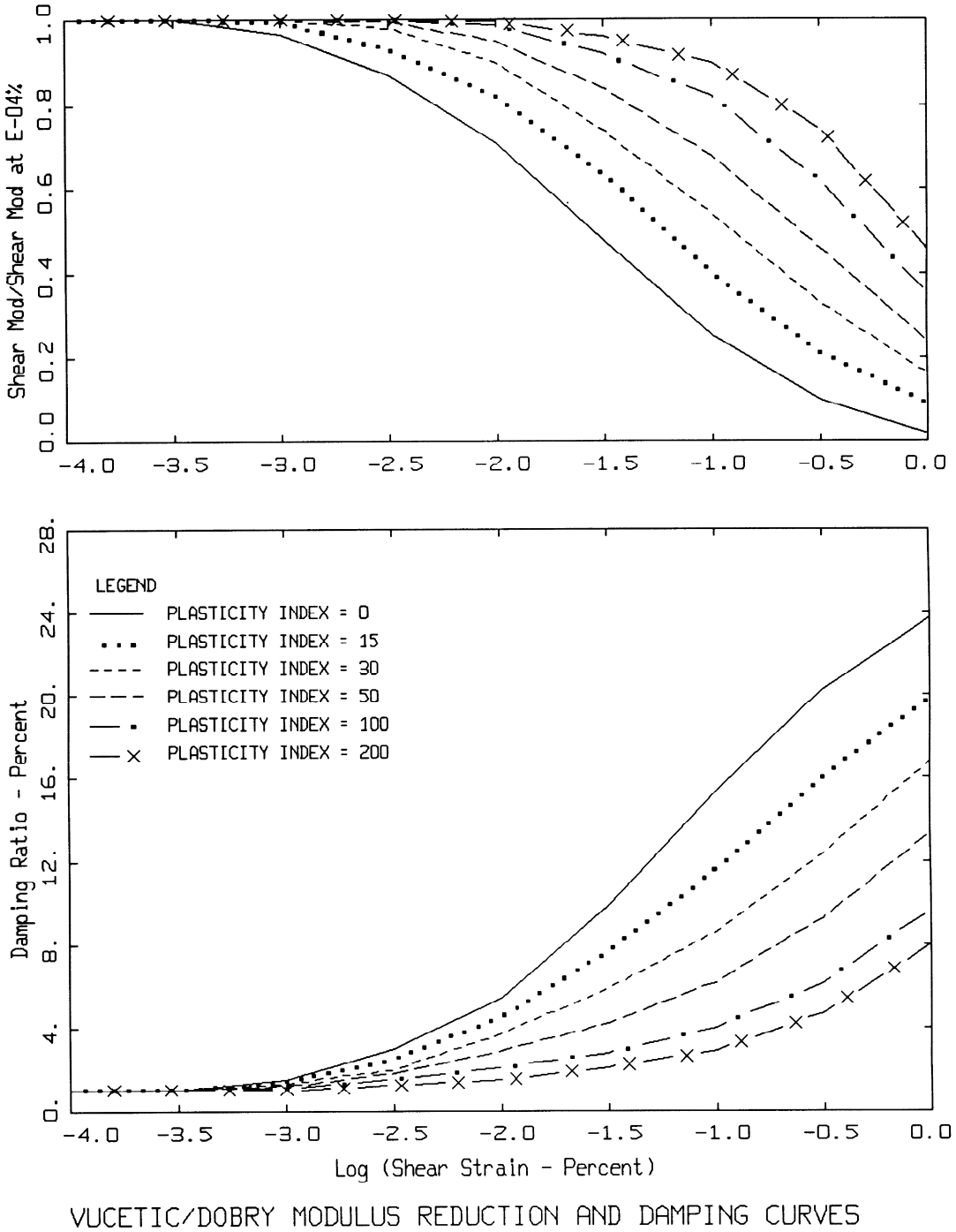


Figure 4. Generic G/Gmax and hysteretic damping curves for cohesive soil (Bay Mud, Old Bay Clay) site conditions (Vucetic and Dobry, 1991).

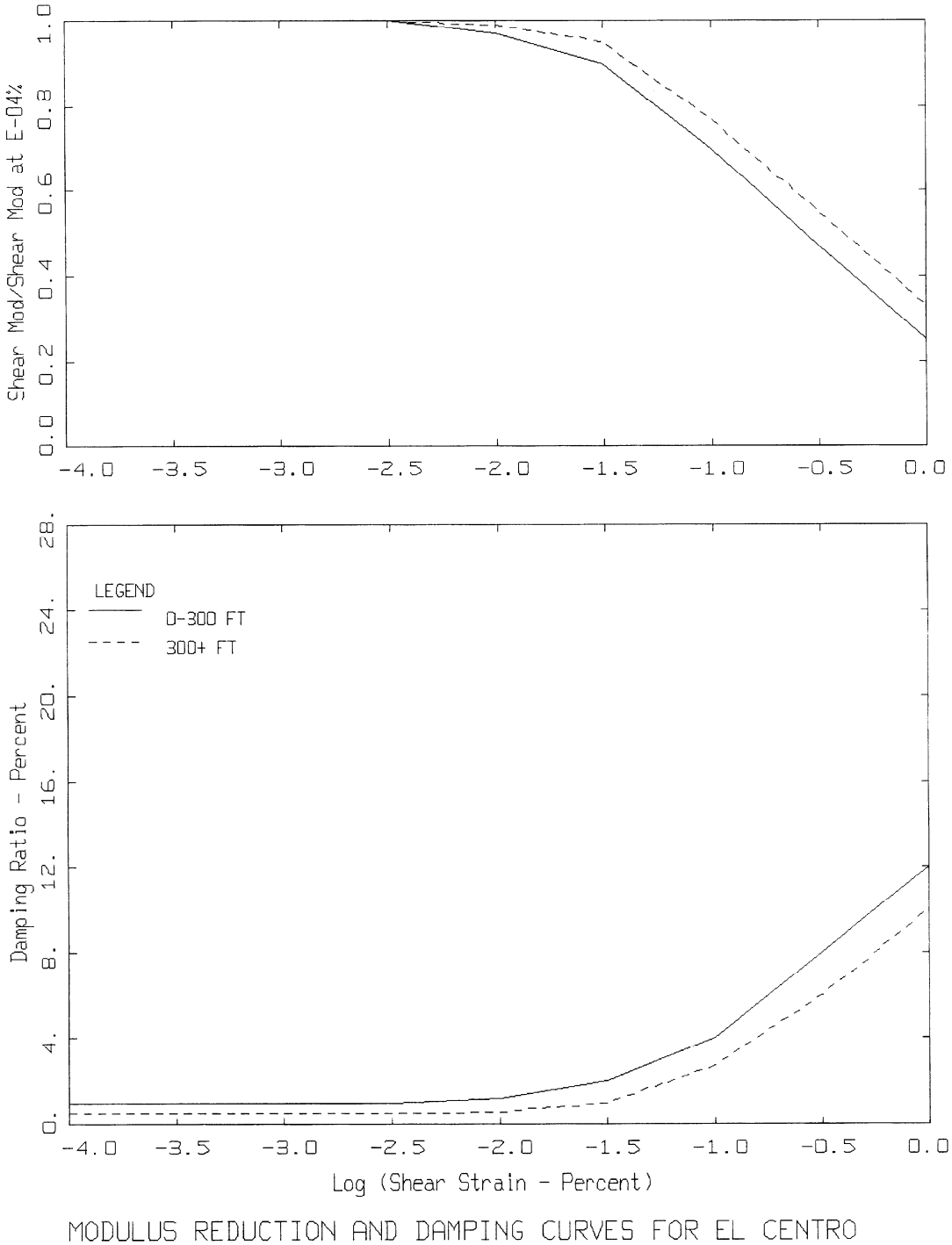
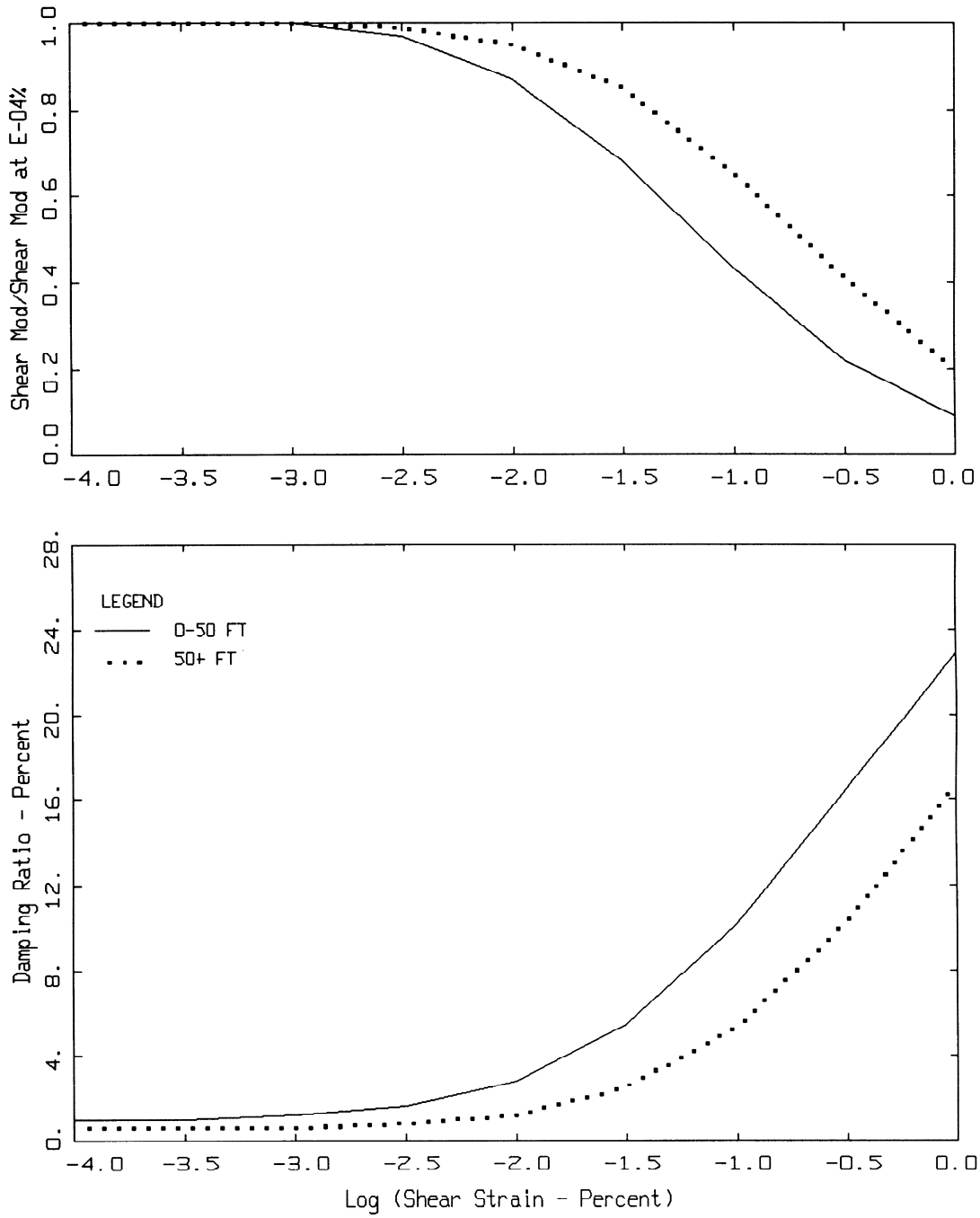
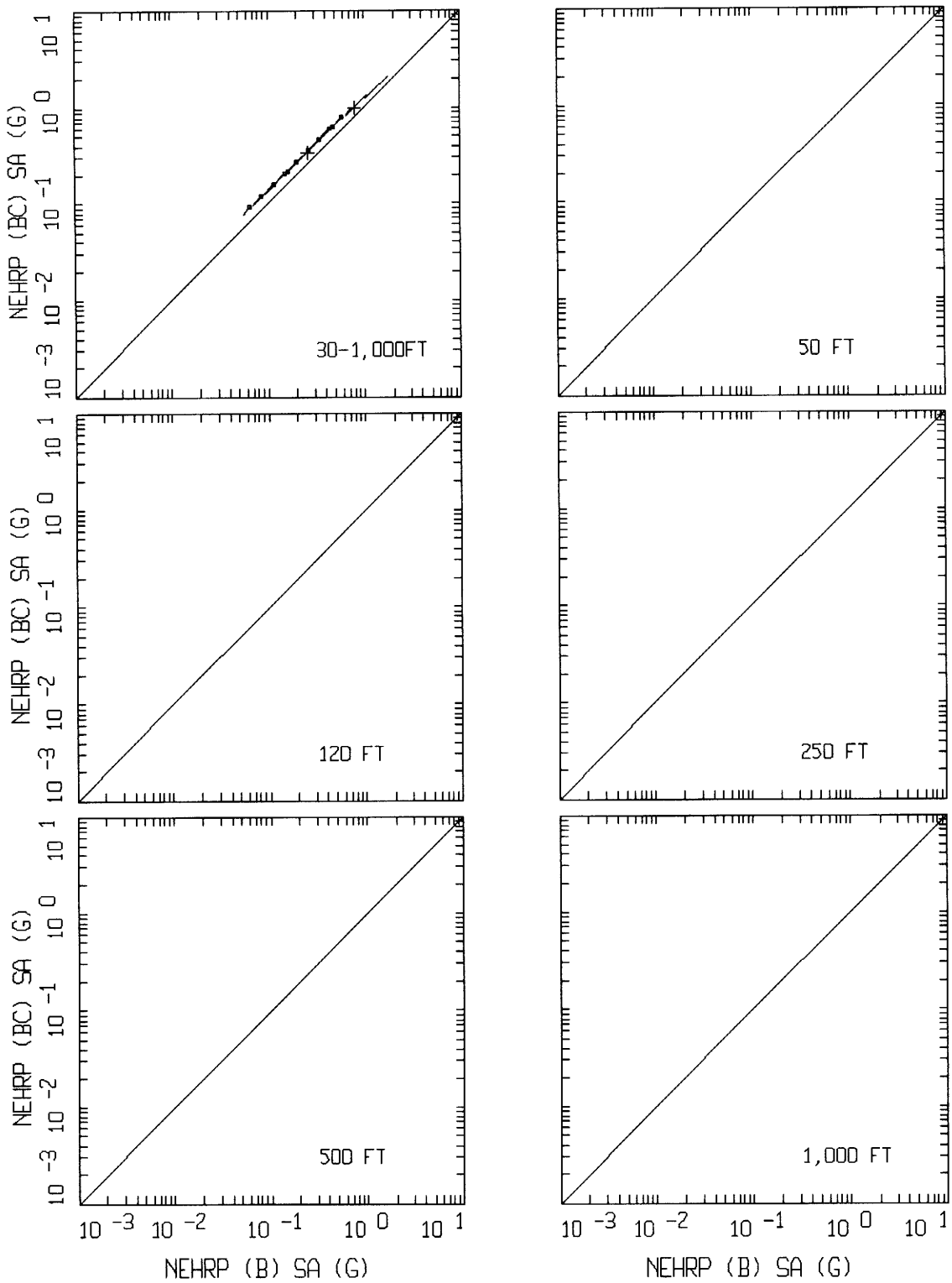


Figure 5. Generic G/Gmax and hysteretic damping curves for Imperial Valley, California soil site conditions (Vucetic and Dobry, 1991).



MODULUS REDUCTION AND DAMPING CURVES FOR COHESIONLESS SOILS

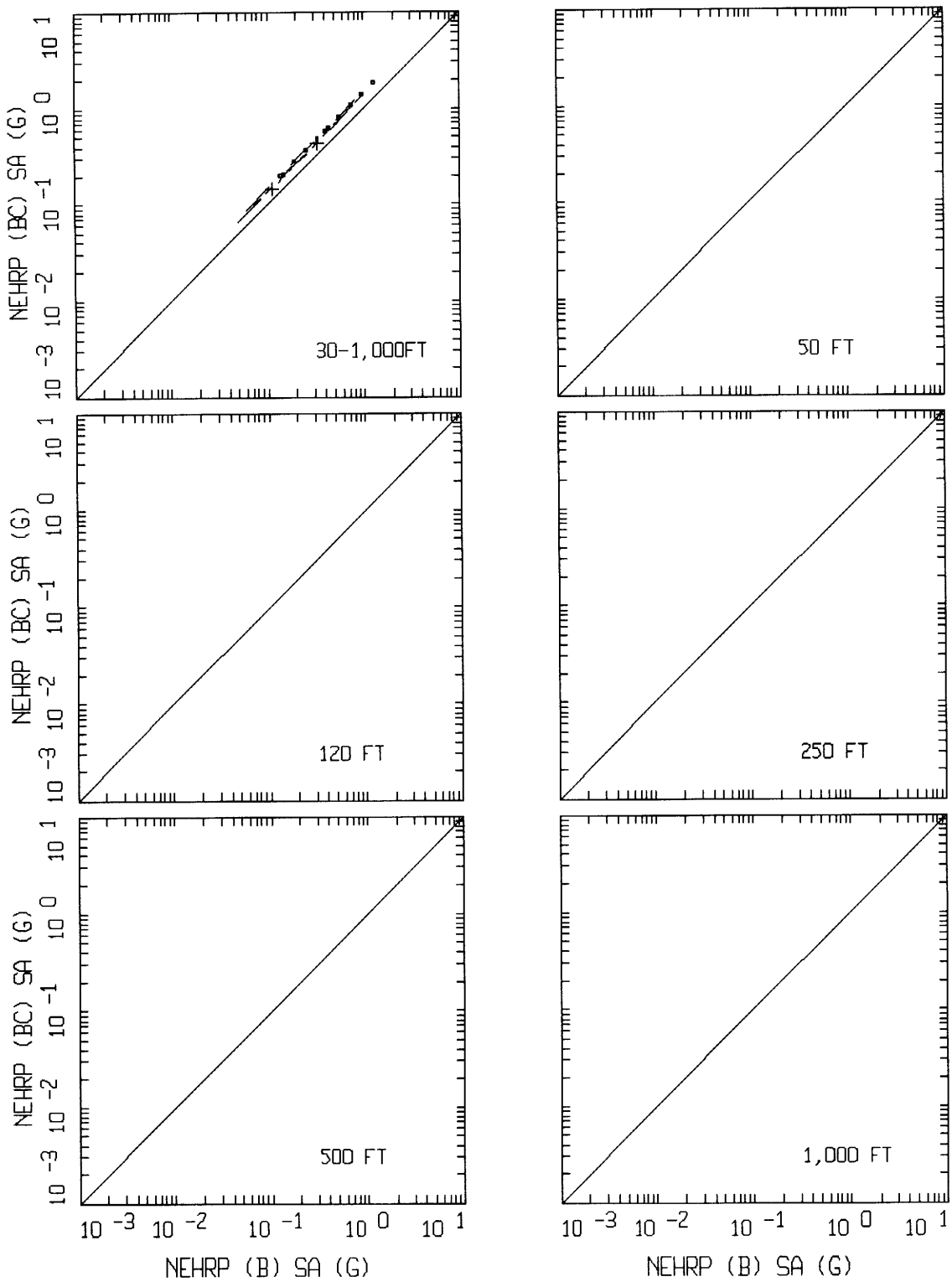
Figure 6. Generic G/Gmax and hysteretic damping curves for Peninsular Range cohesionless soil site conditions (Silva et al., 1997).



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

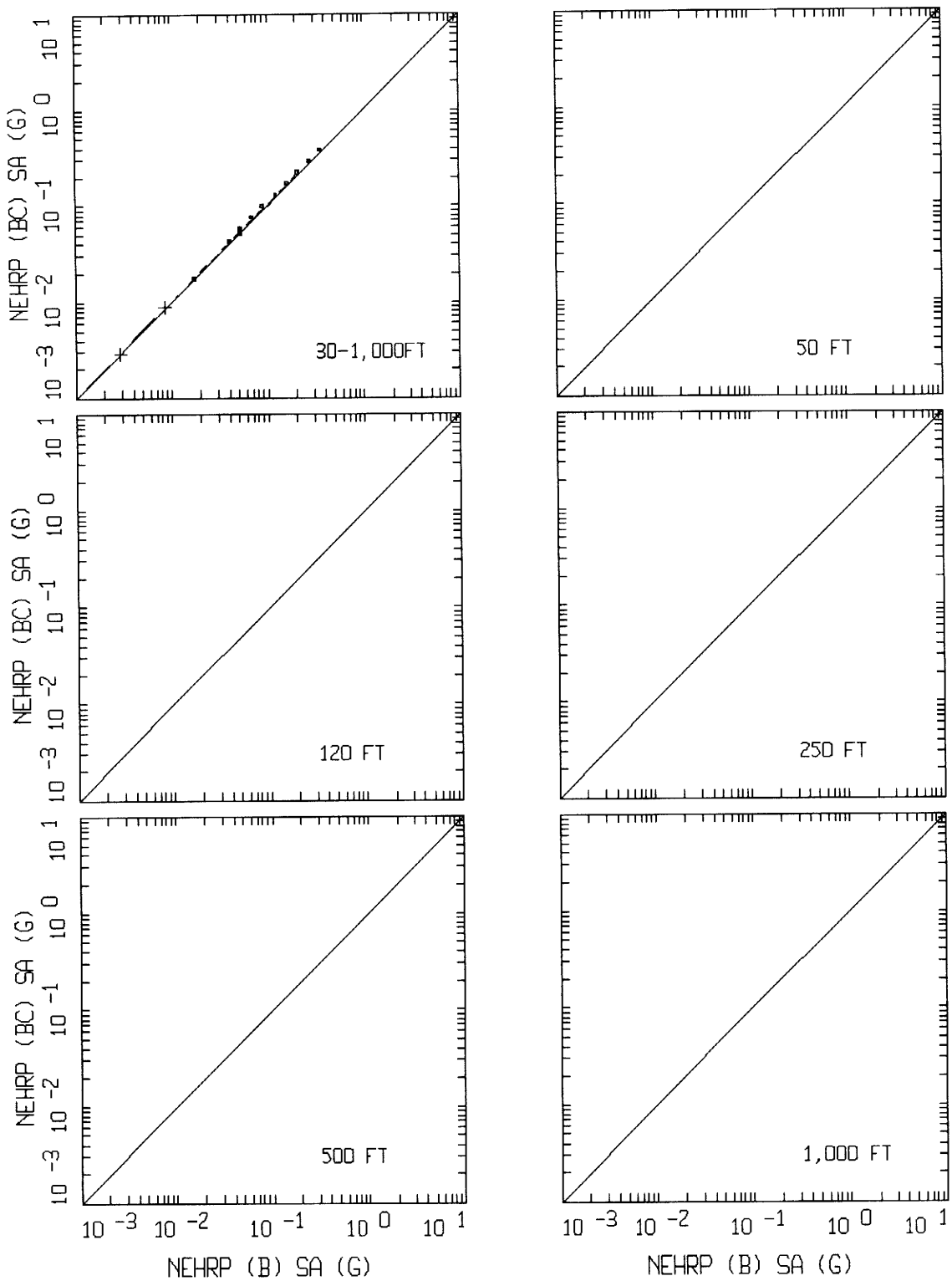
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

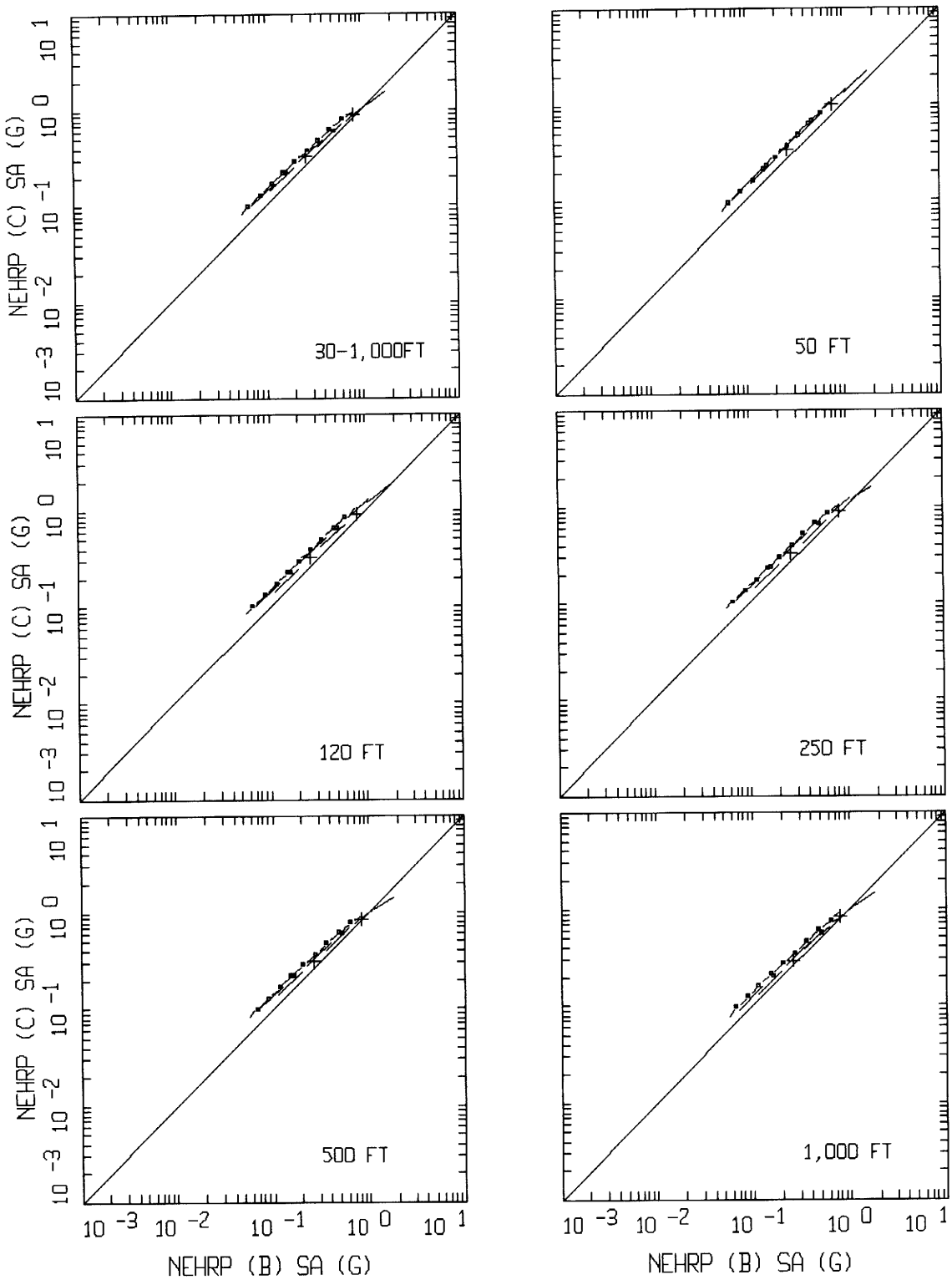
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

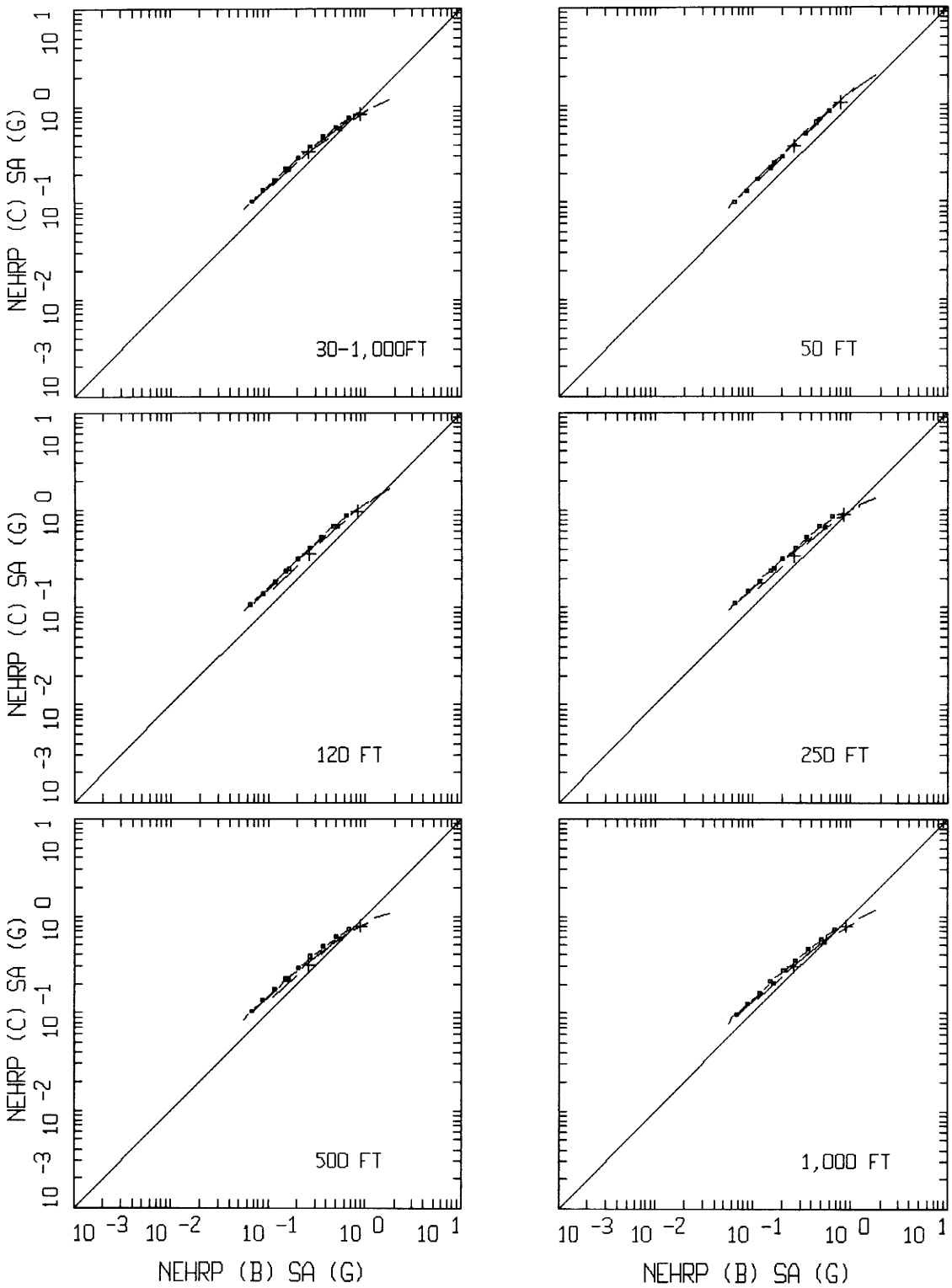
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

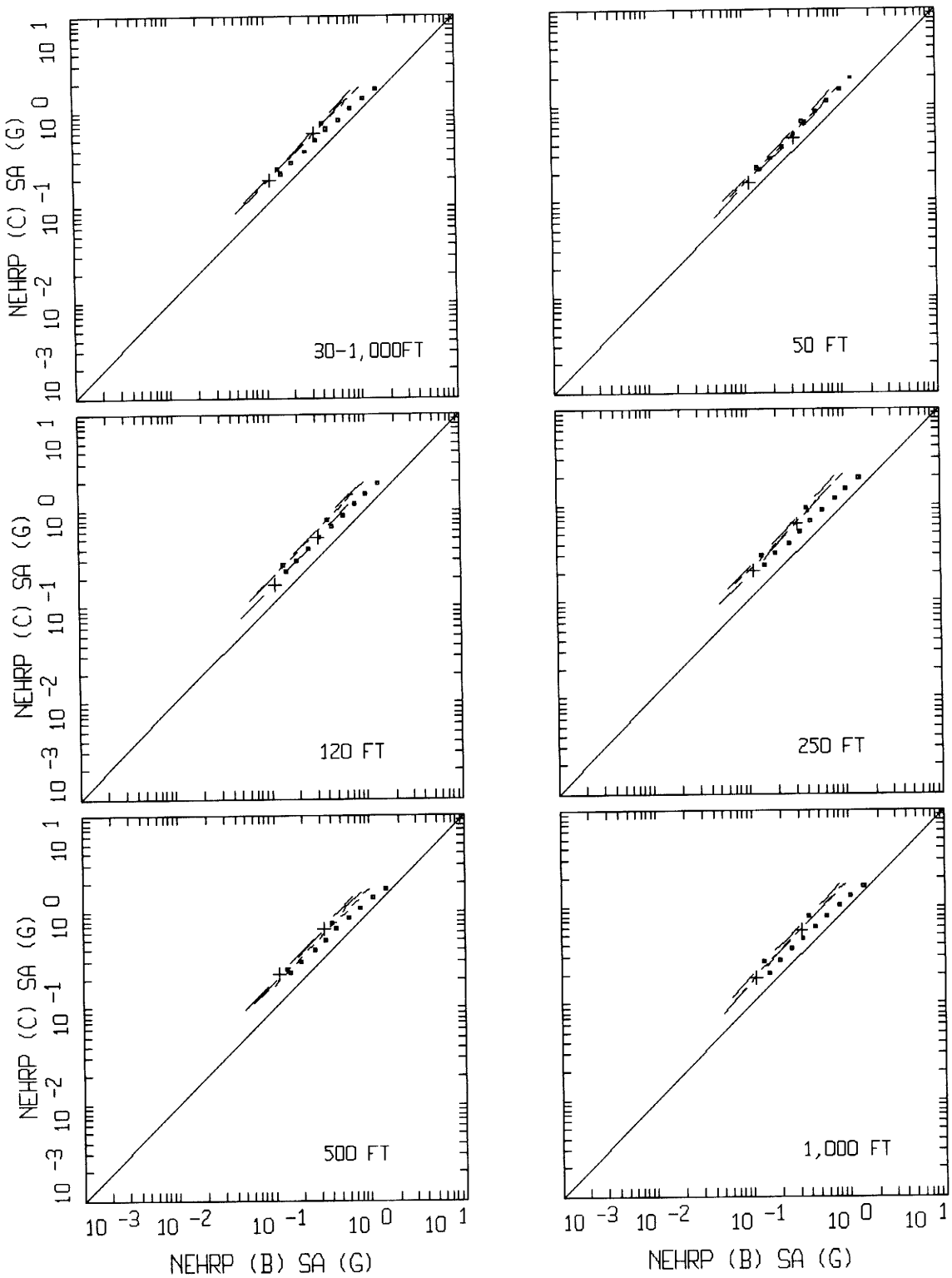
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

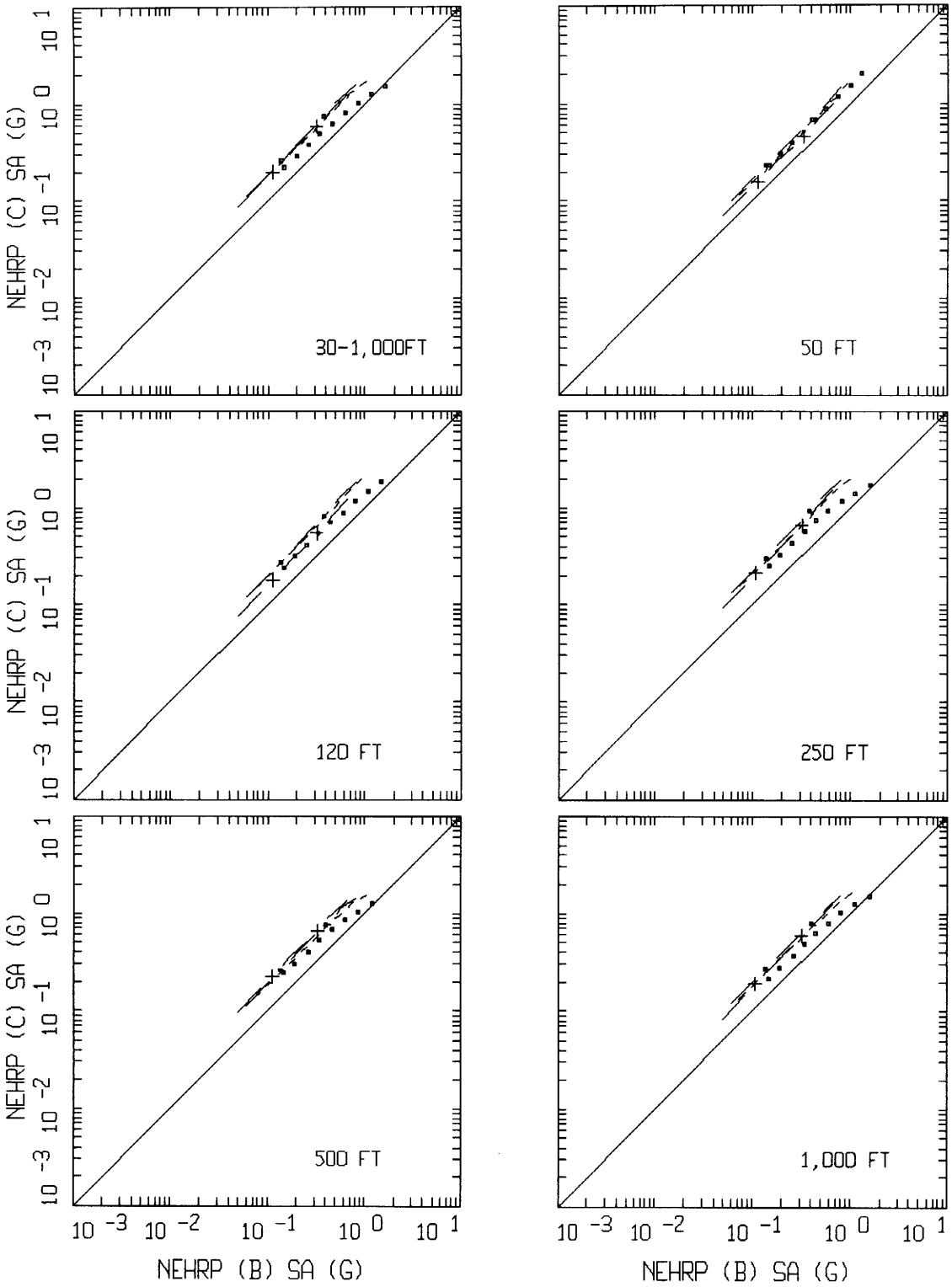
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

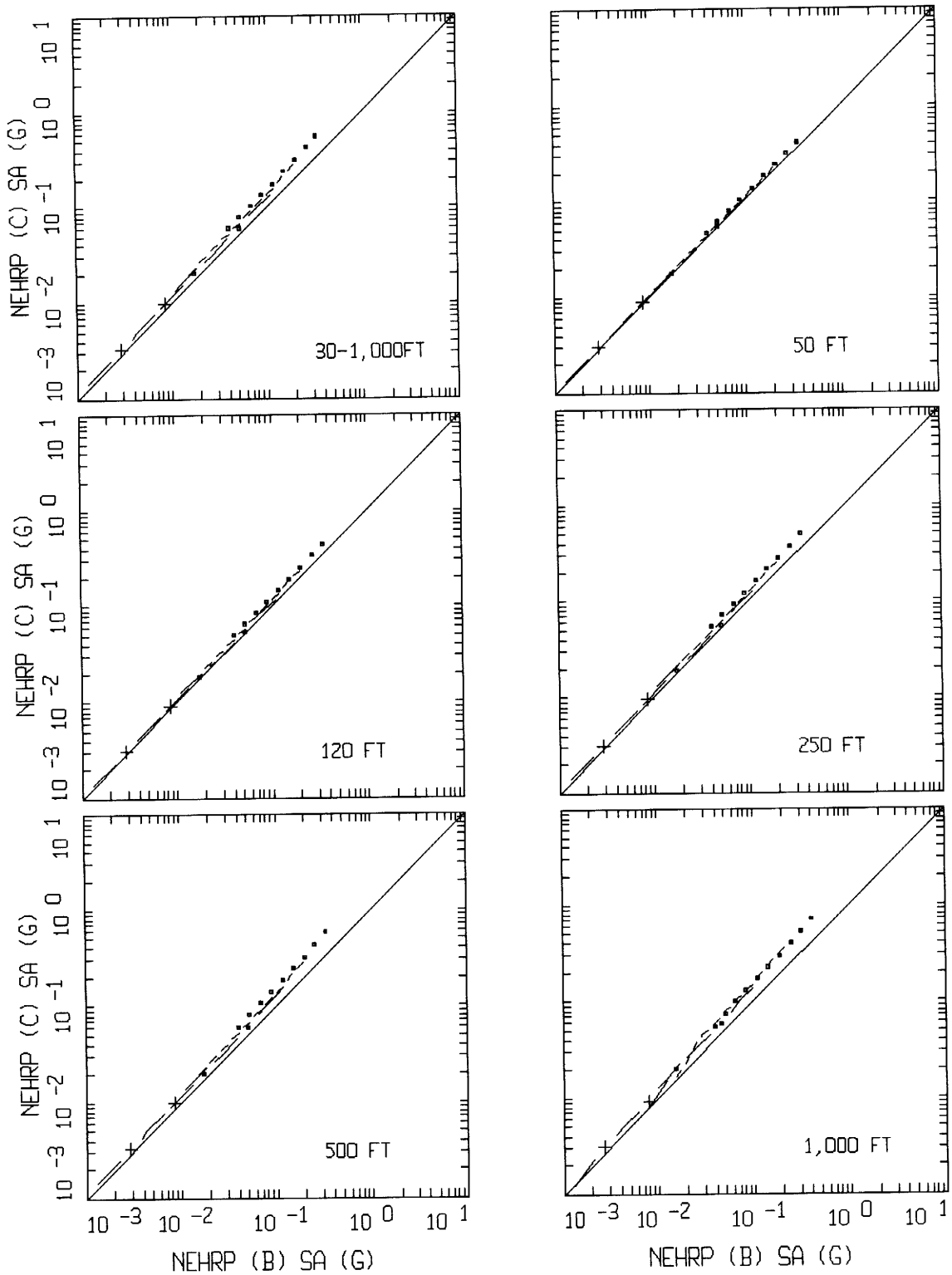
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

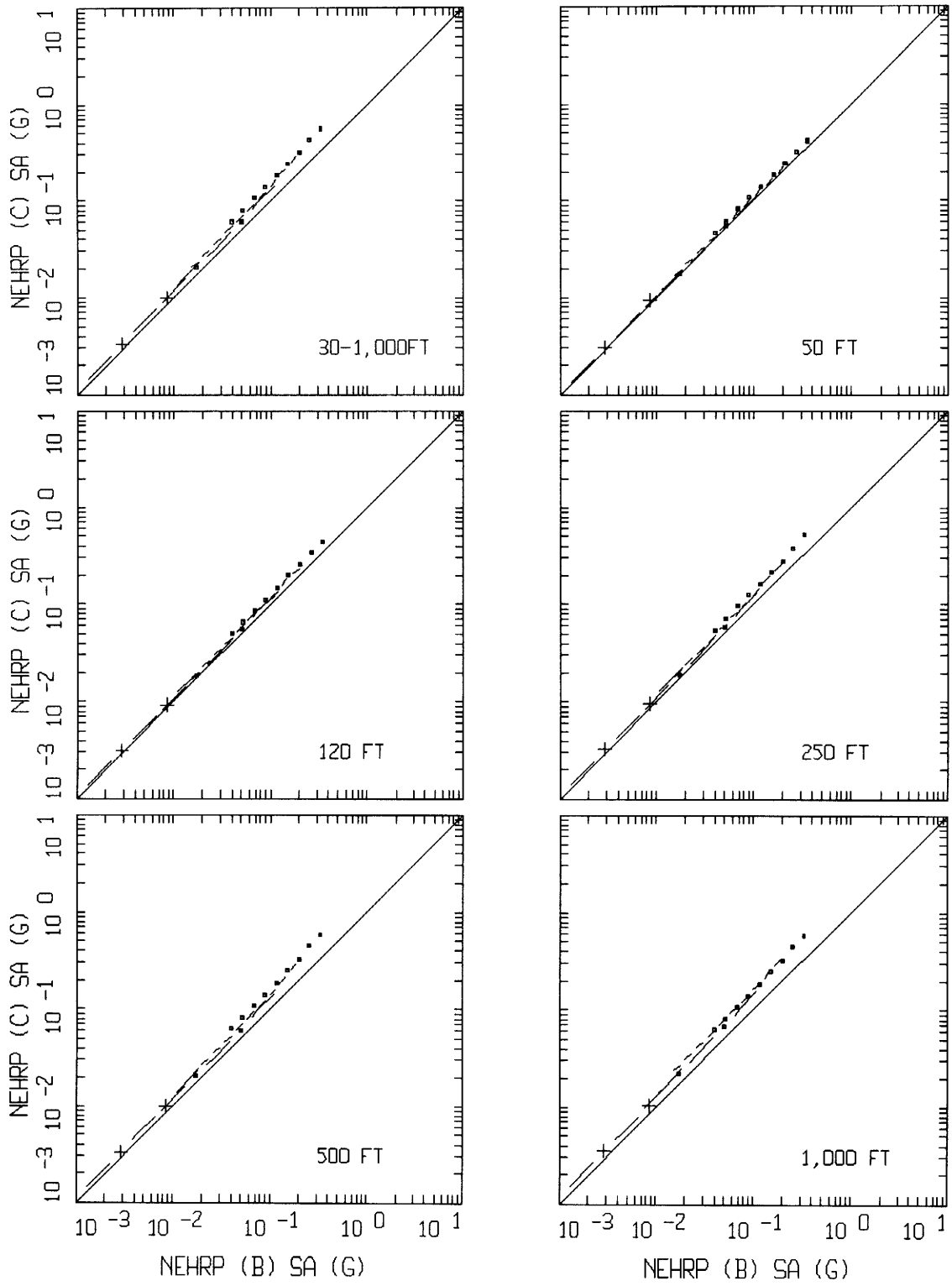
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

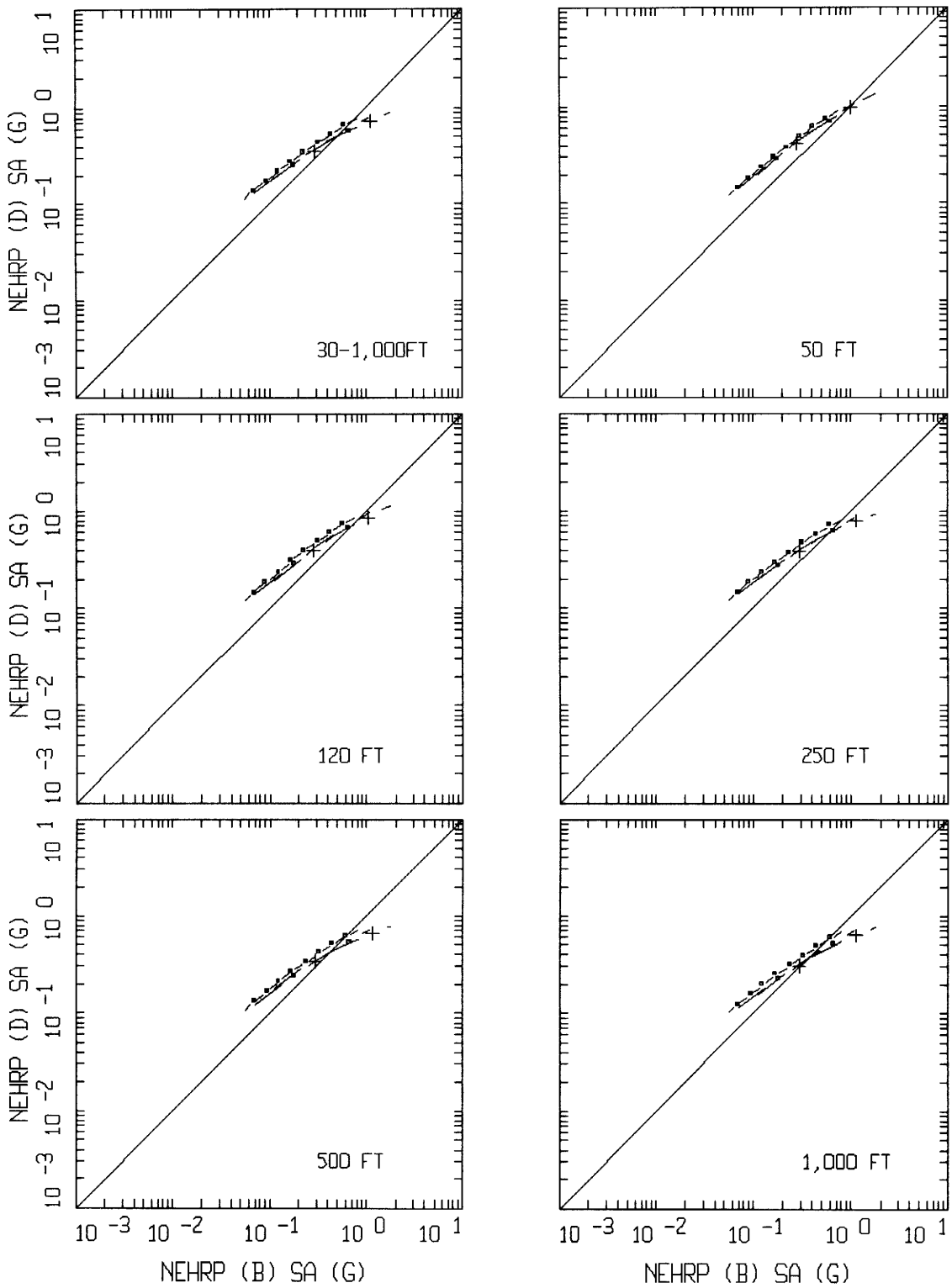
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

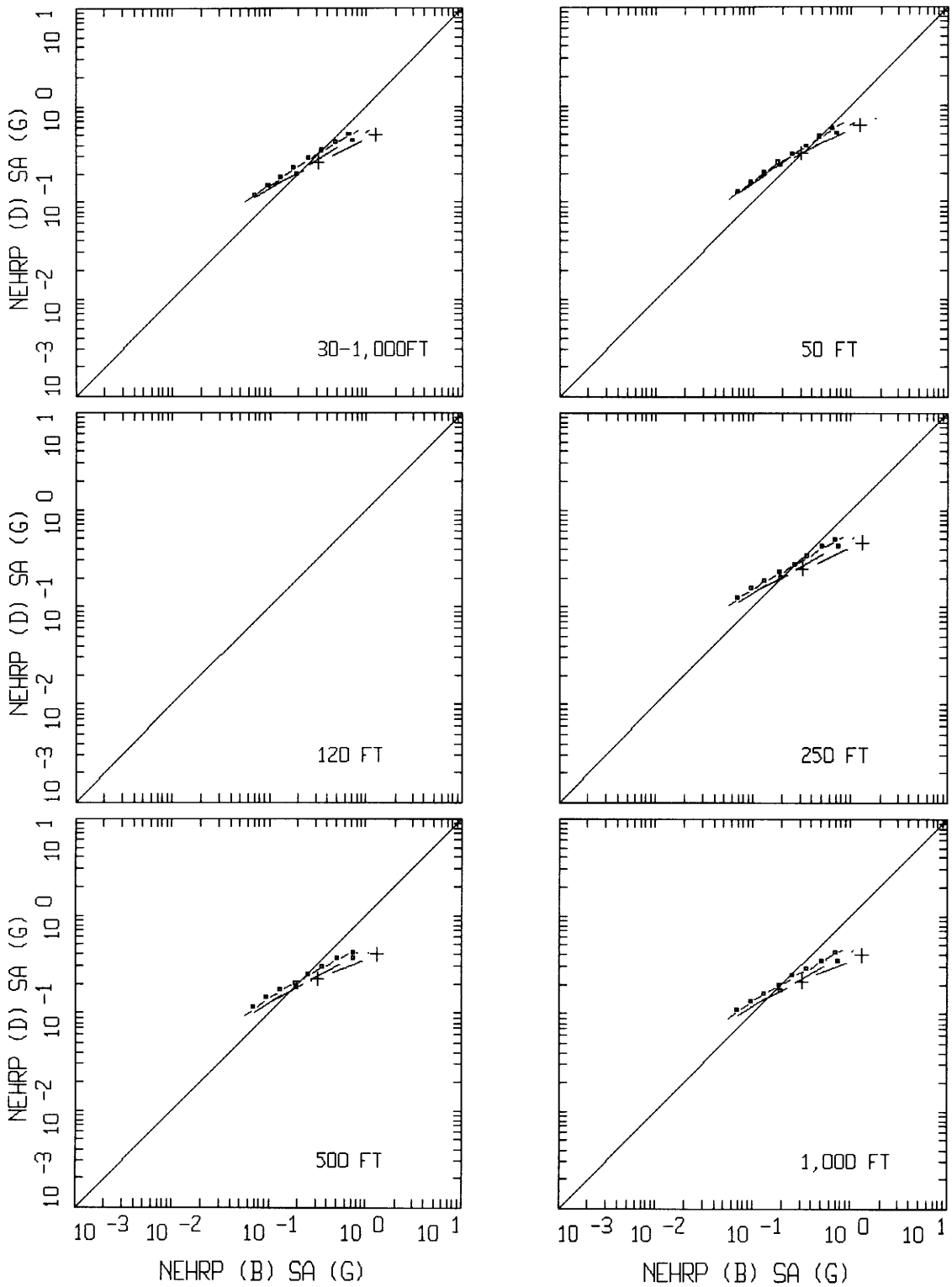
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

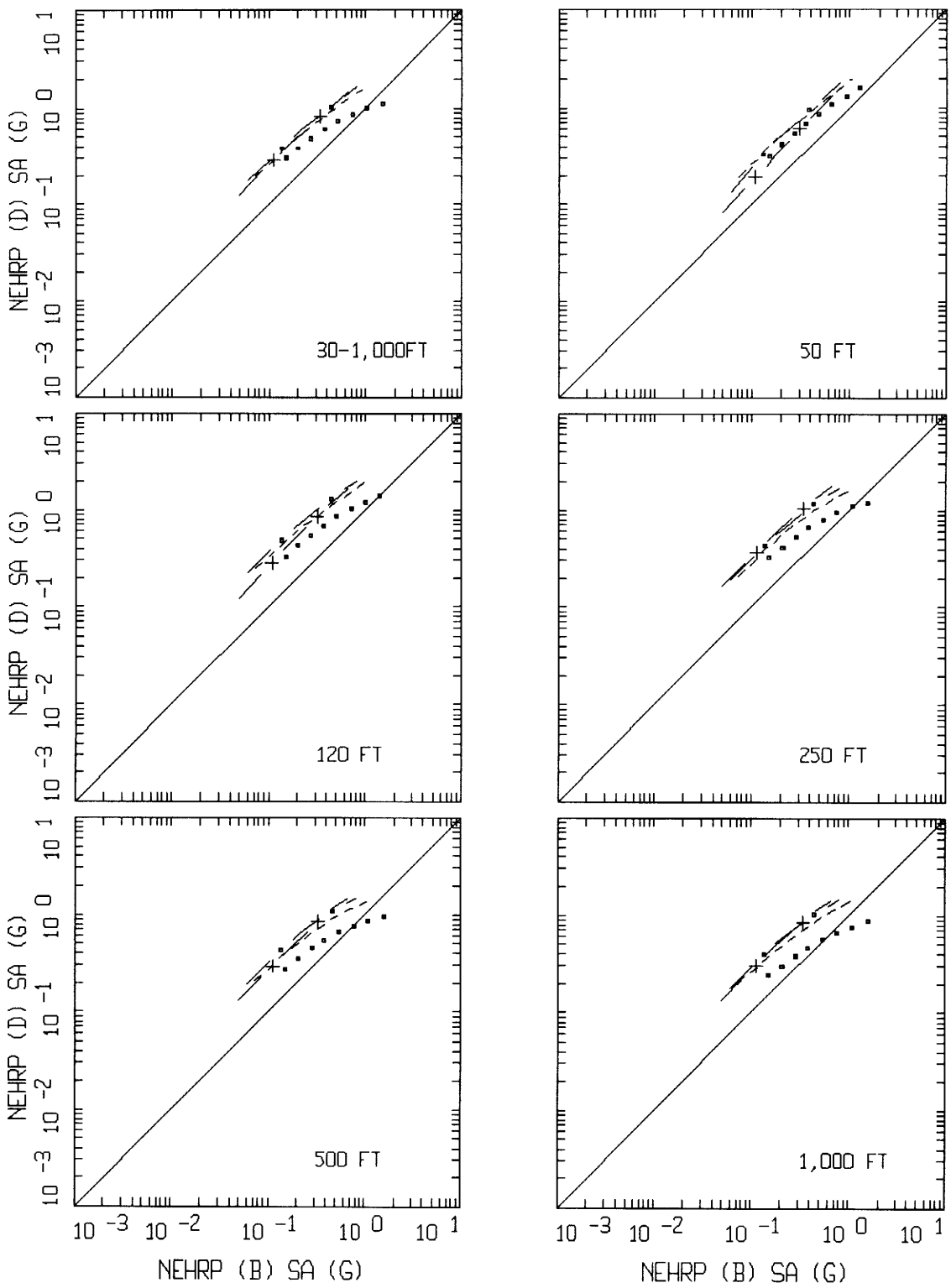
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

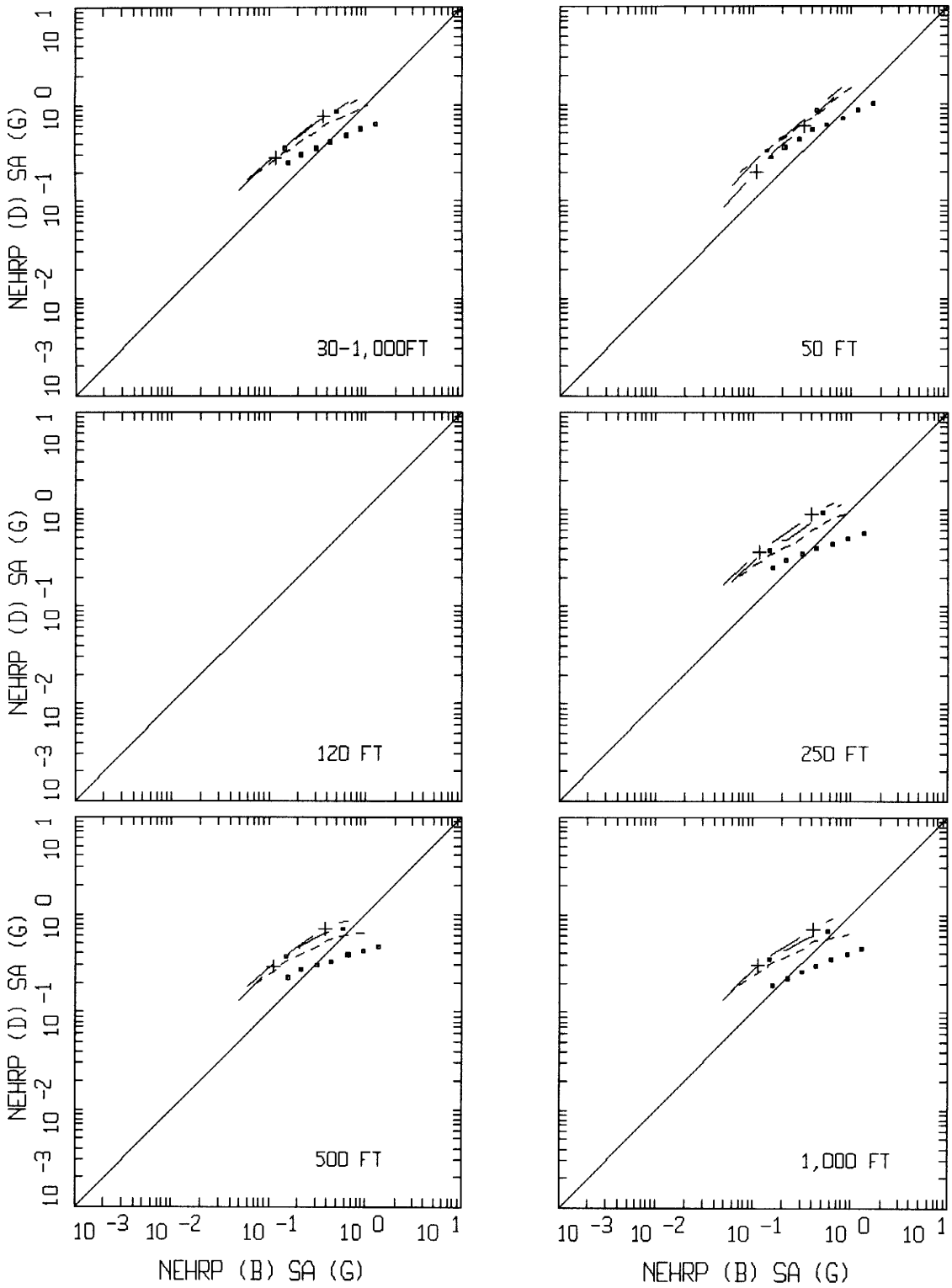
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

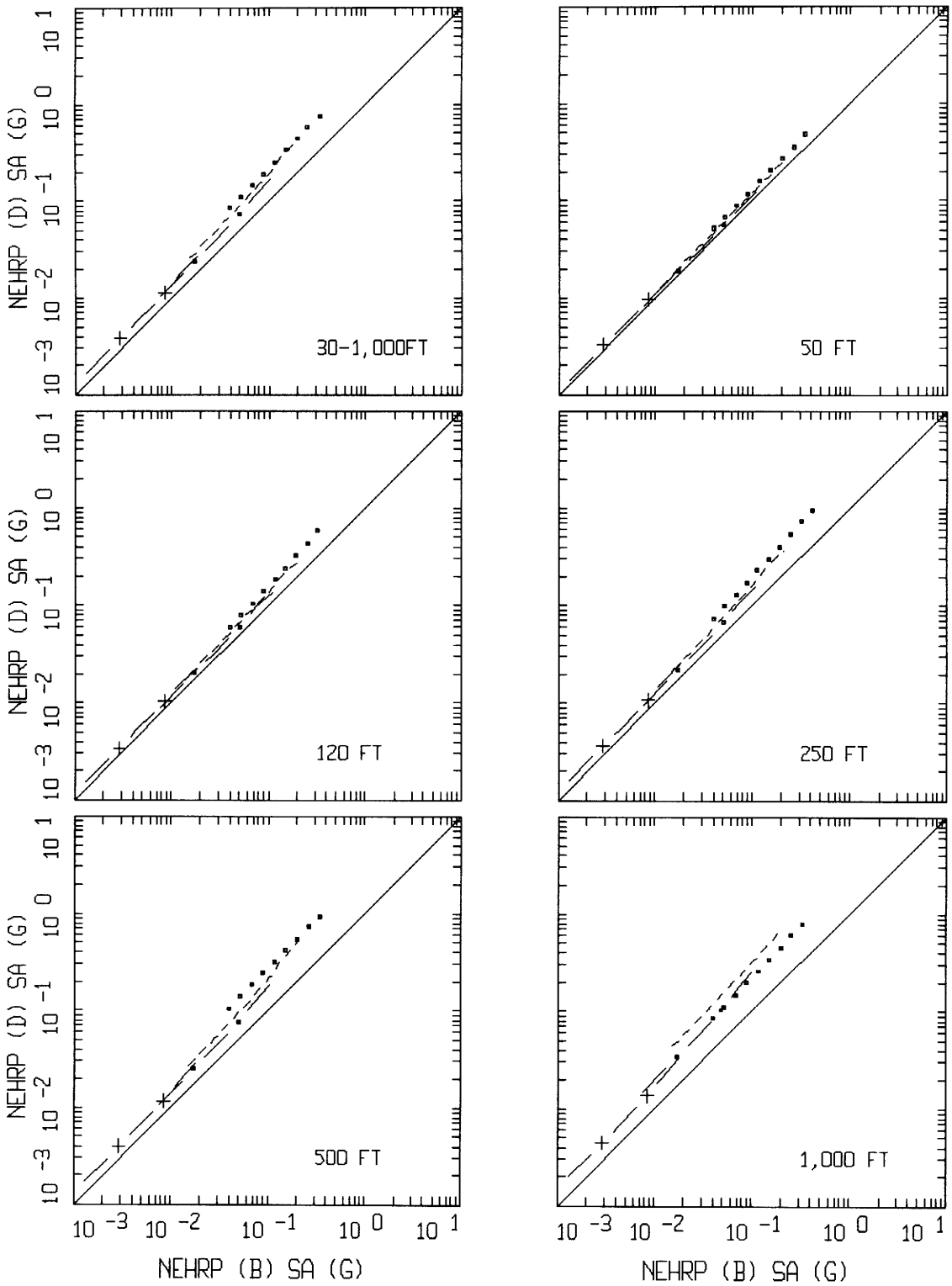
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

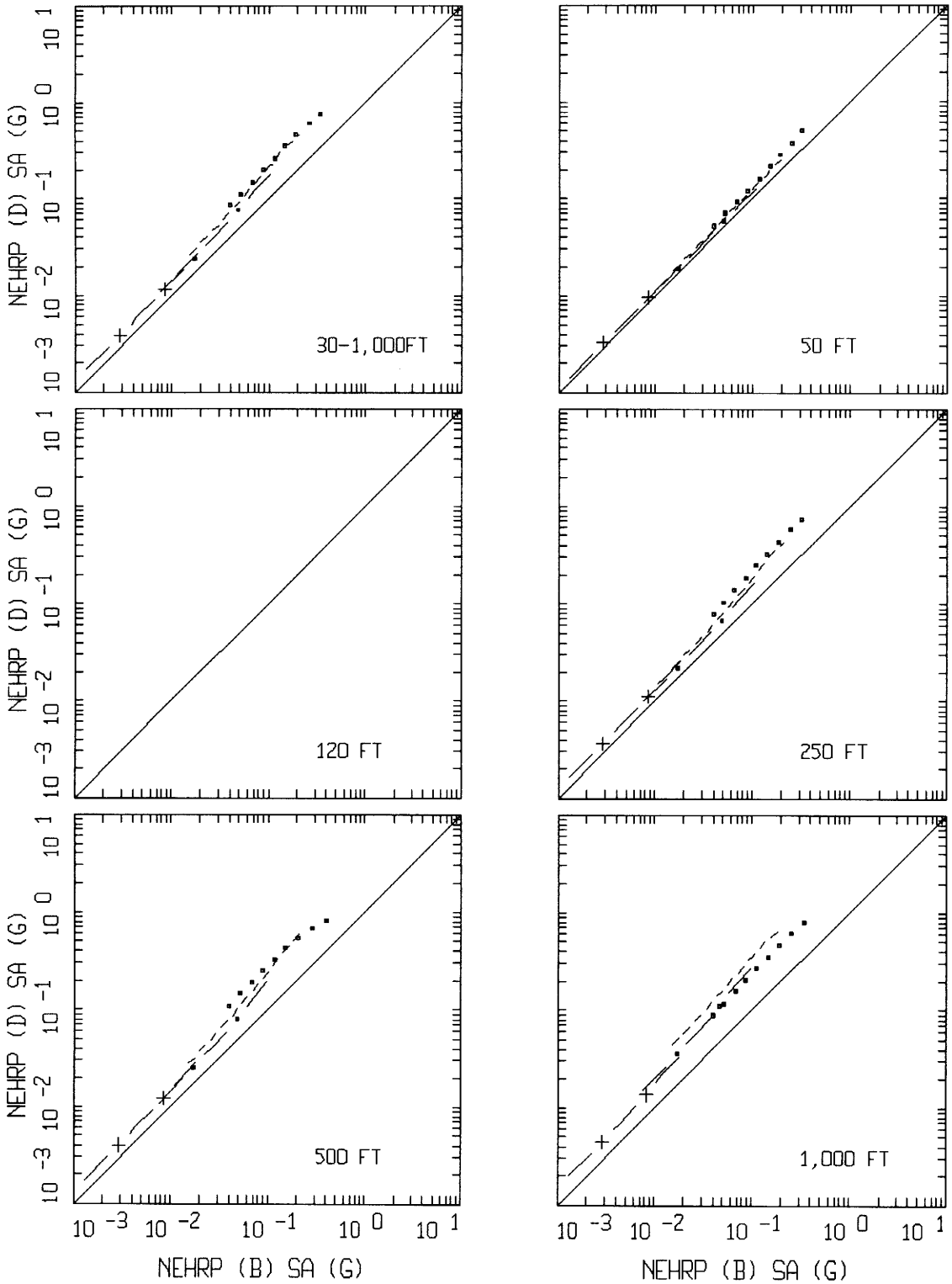
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

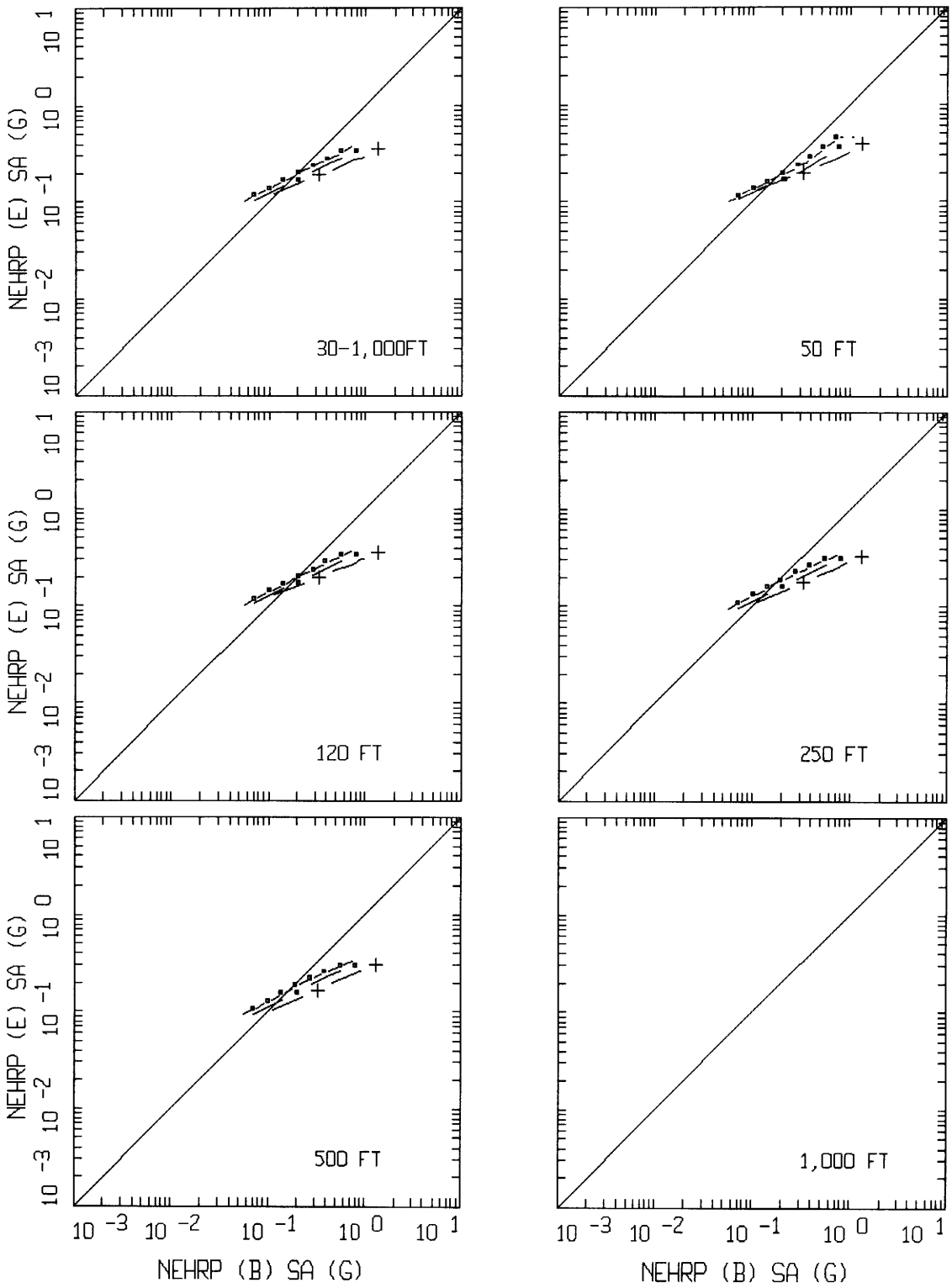
- FREQ = 0.5 HZ
- FREQ = 0.3 HZ
- FREQ = 0.2 HZ
- FREQ = 0.1 HZ
- UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

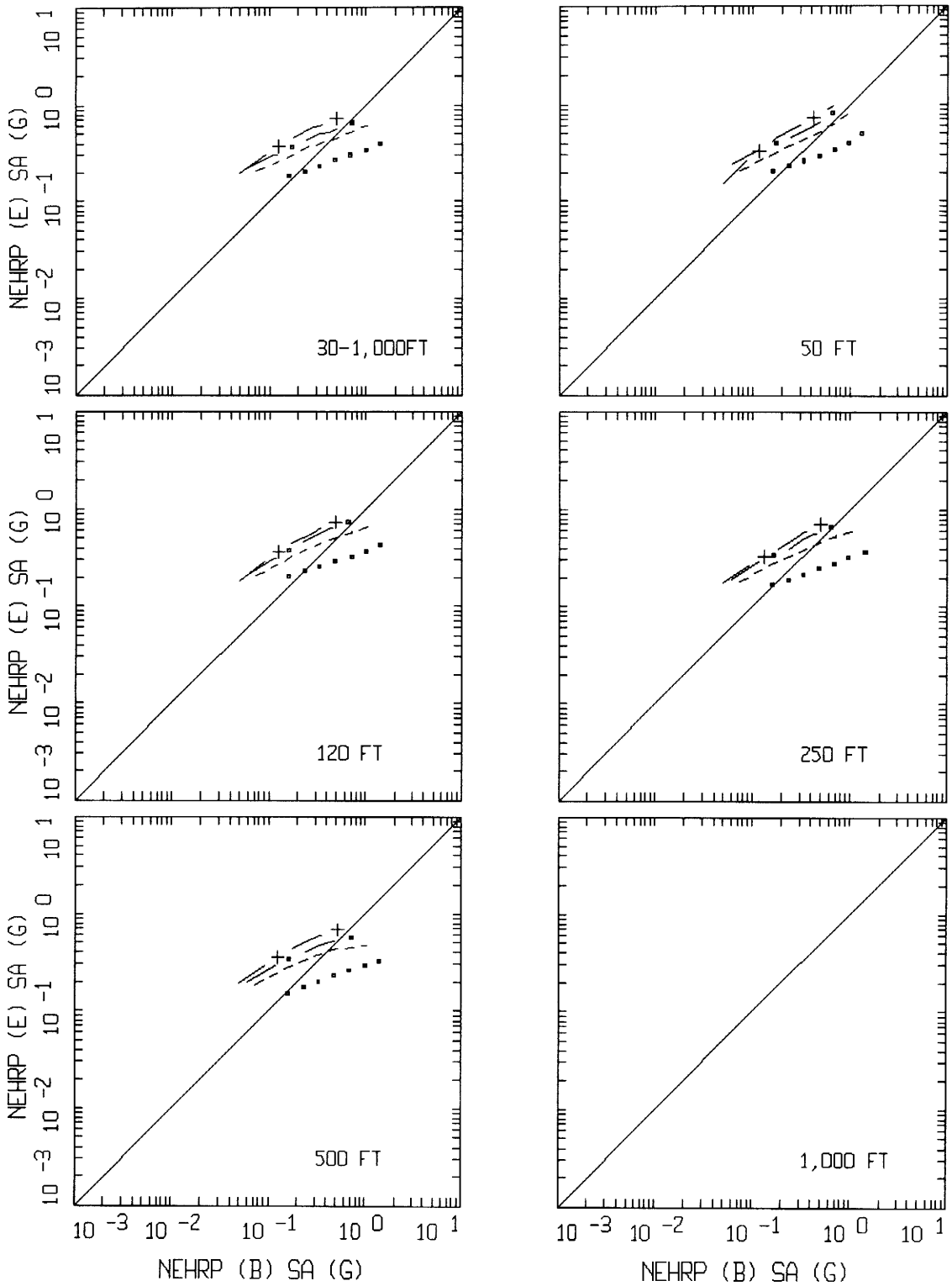
- FREQ = 0.5 HZ
- FREQ = 0.3 HZ
- FREQ = 0.2 HZ
- FREQ = 0.1 HZ
- UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

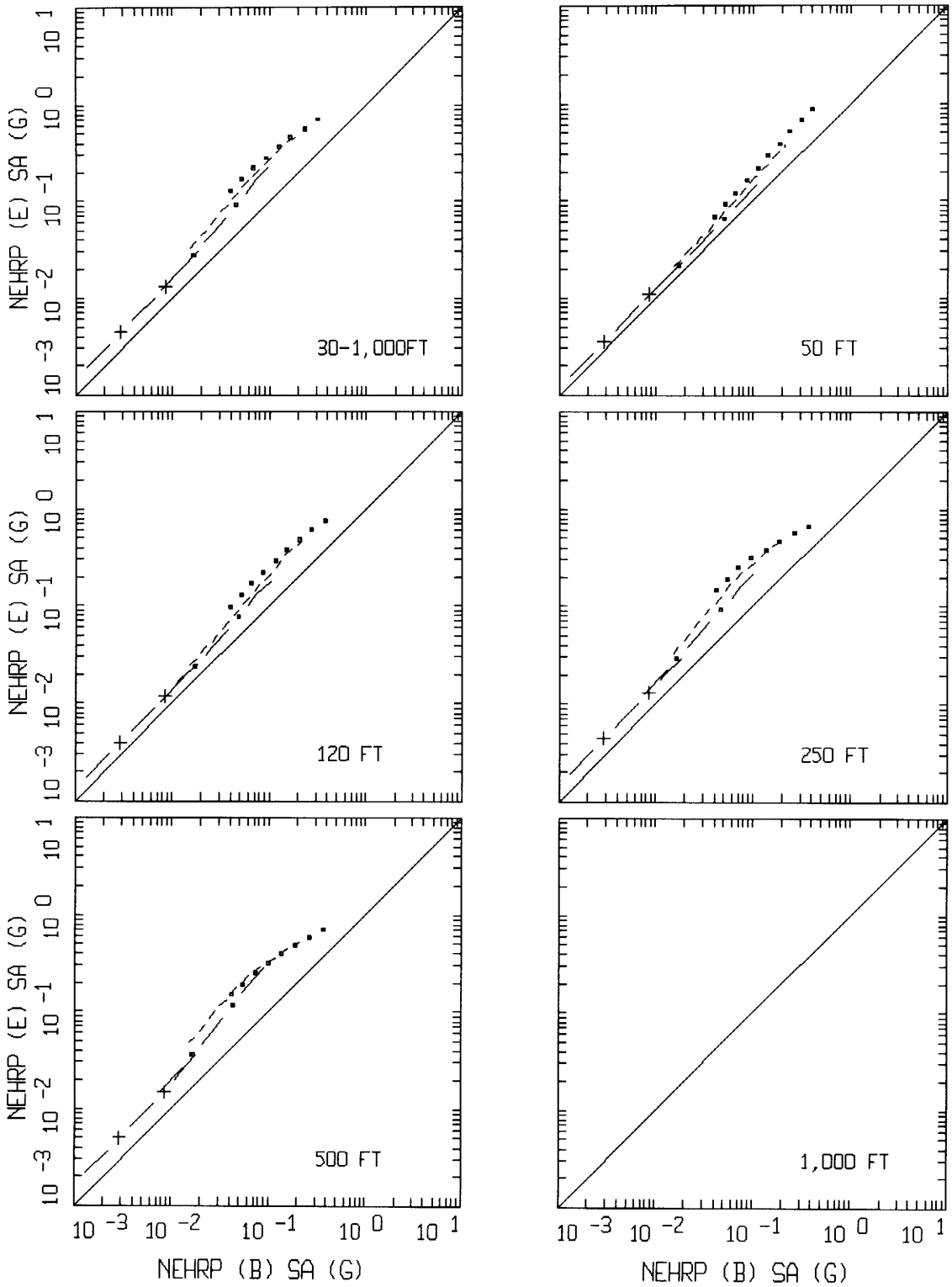
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

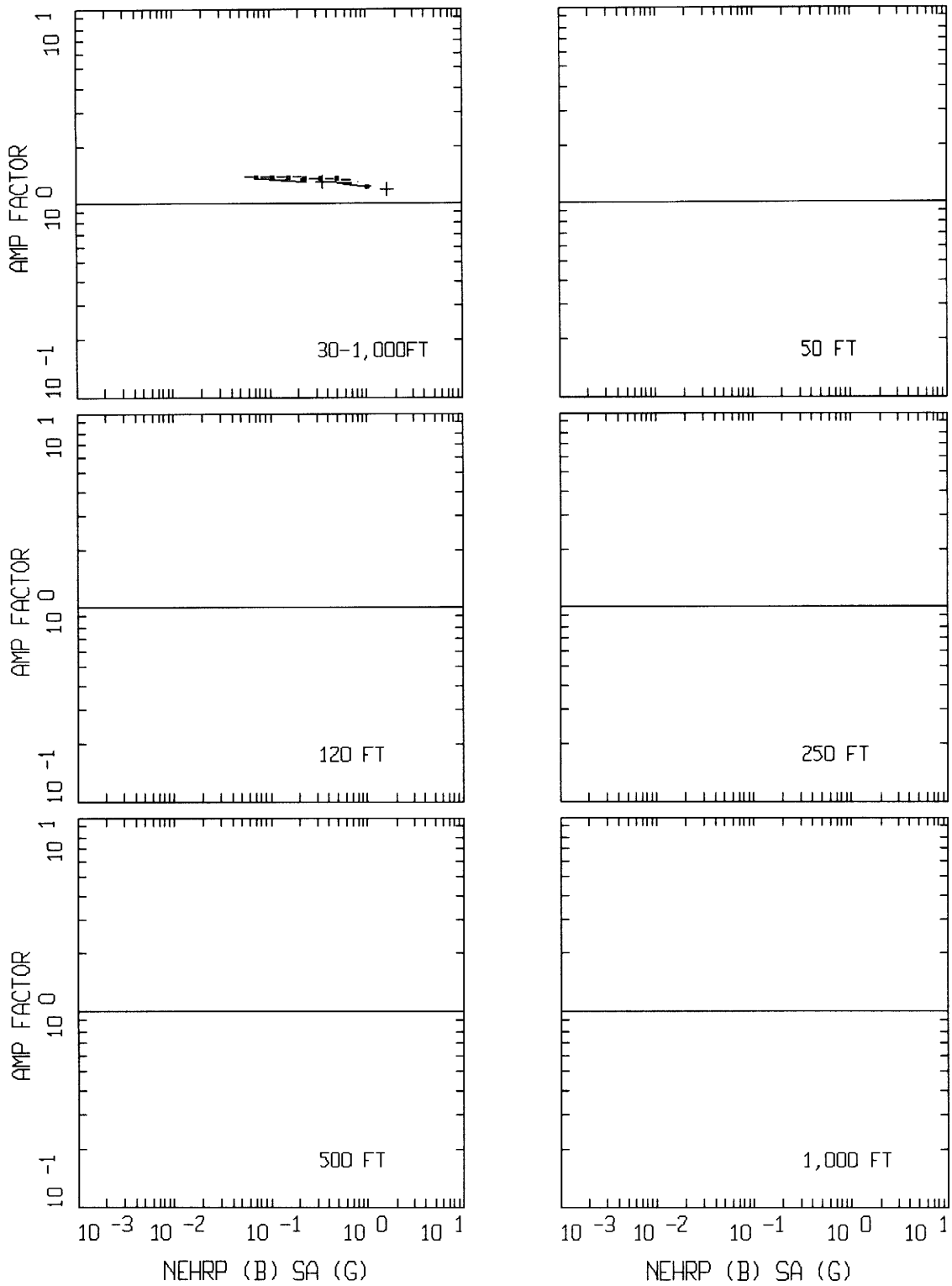
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

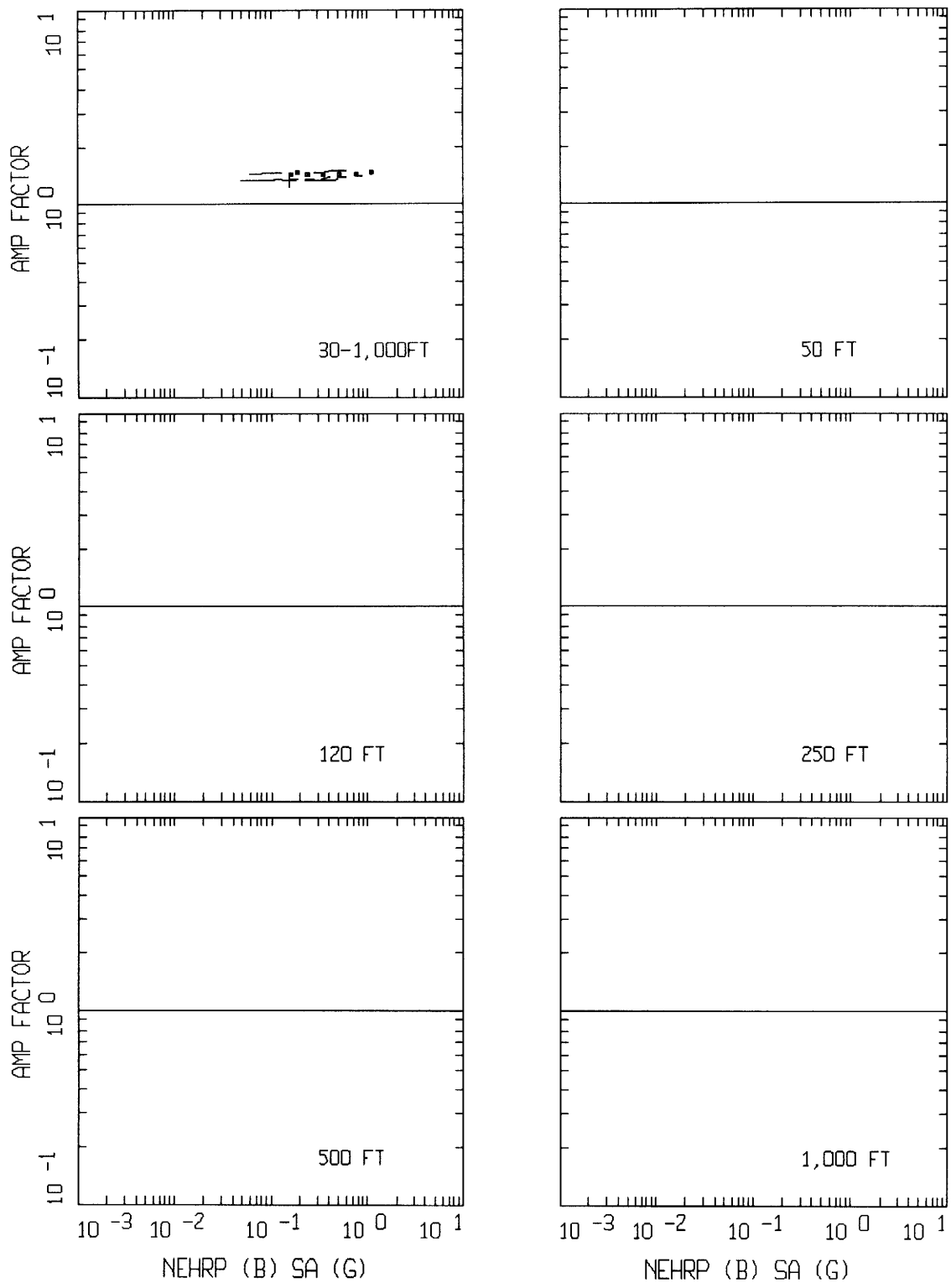
- FREQ = 0.5 HZ
- FREQ = 0.3 HZ
- FREQ = 0.2 HZ
- FREQ = 0.1 HZ
- UNITY LINE



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

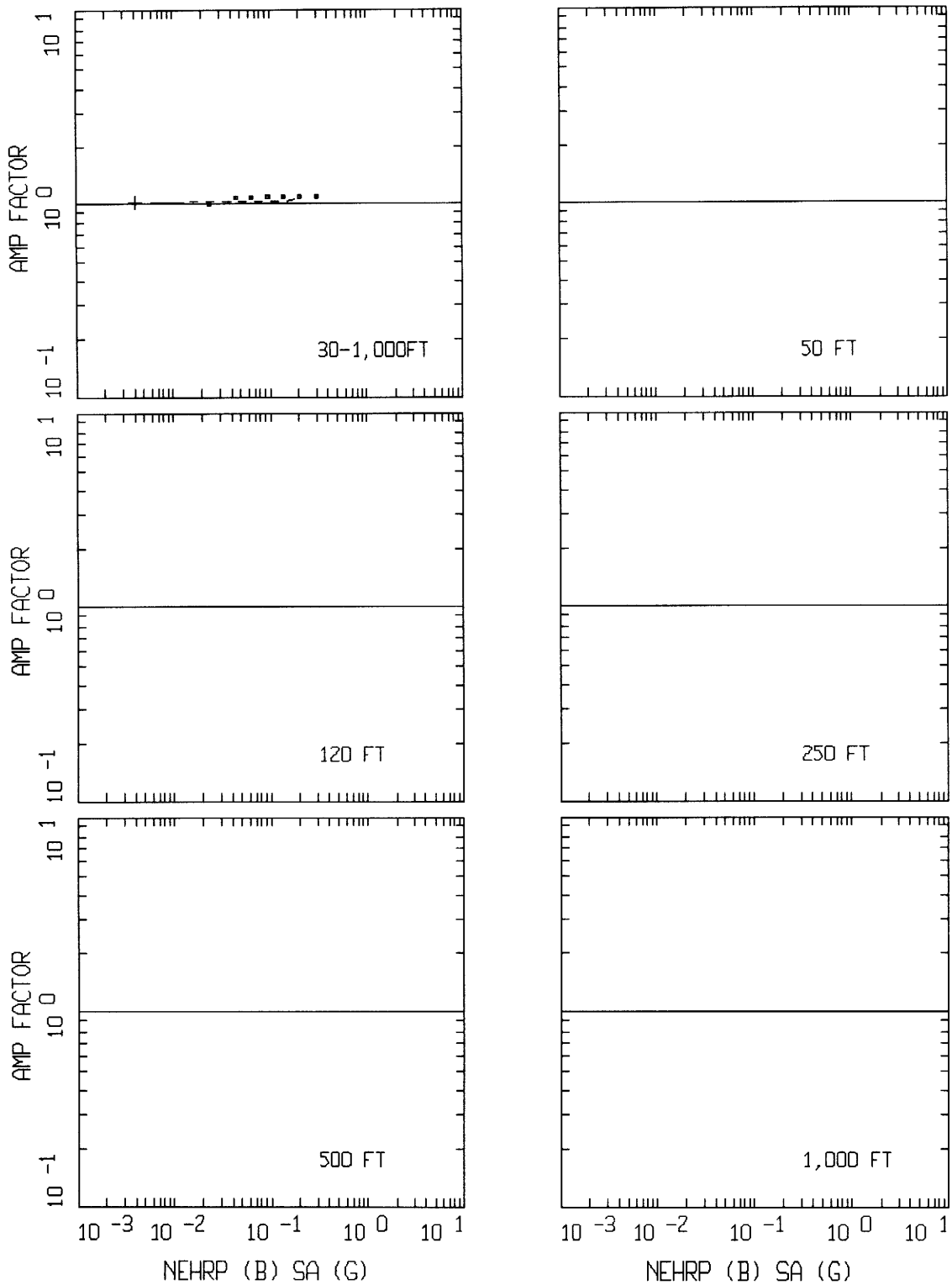
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

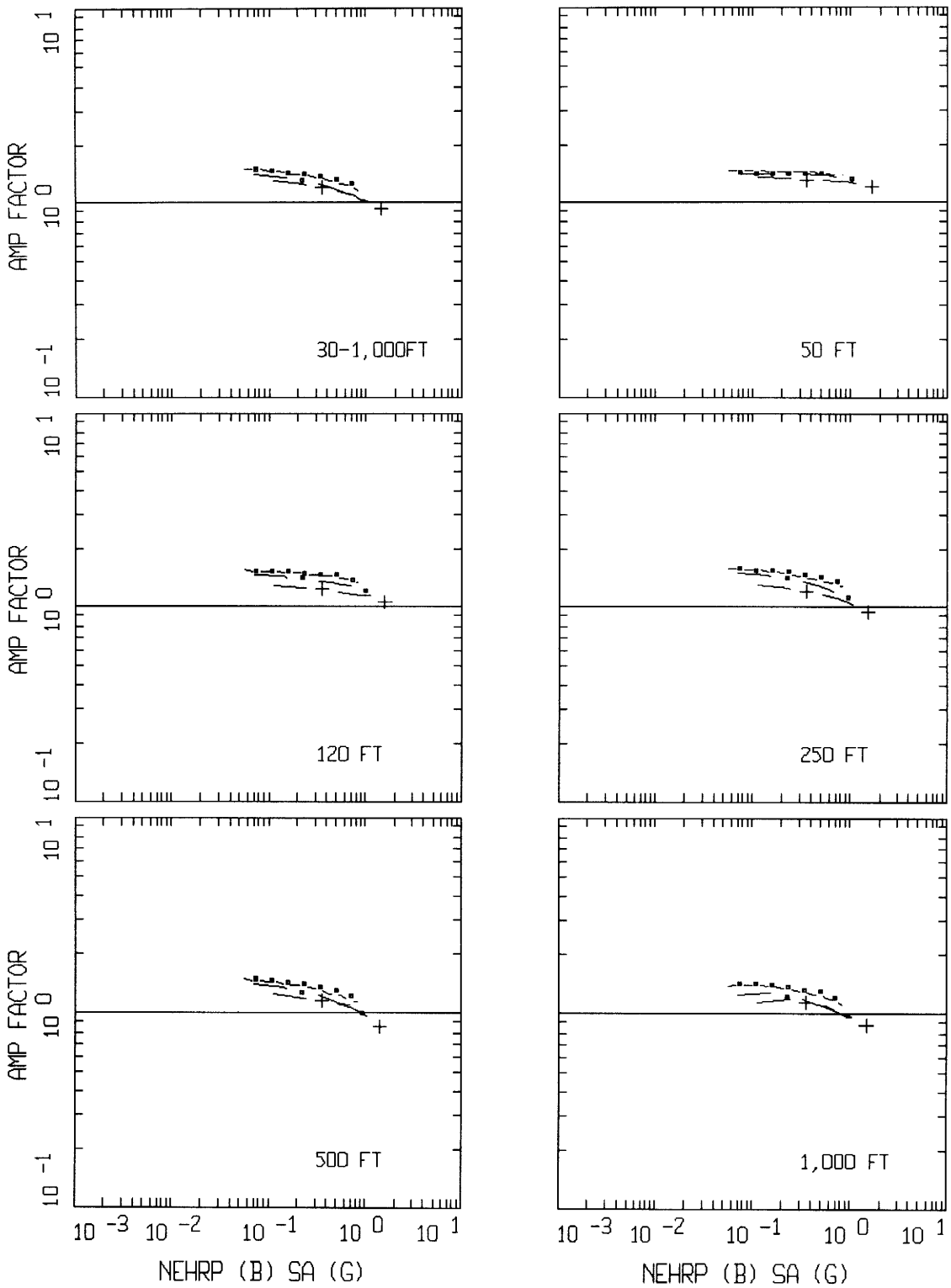
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(BC) / NEHRP(B)
BNL SOIL MODEL

LEGEND

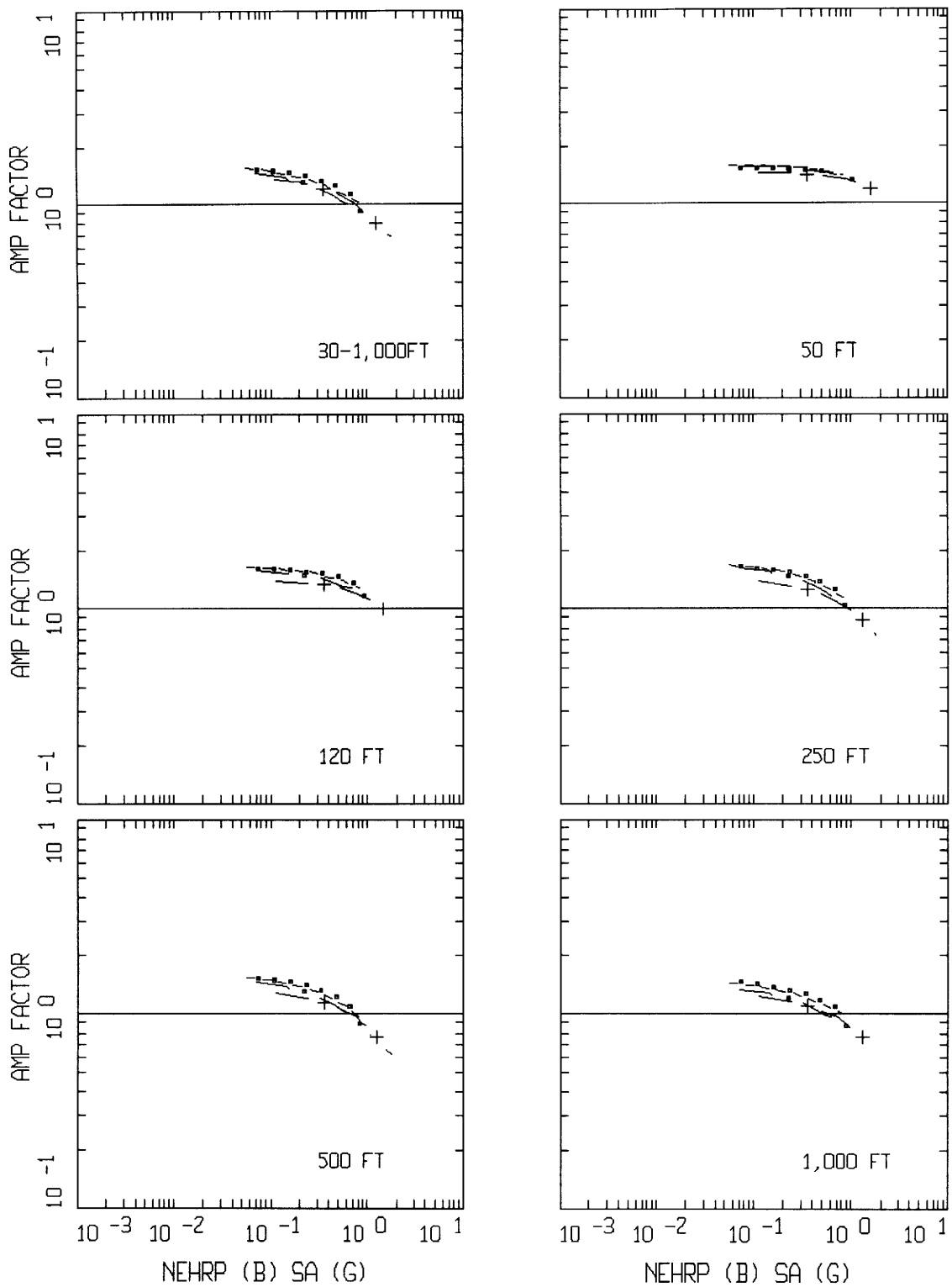
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

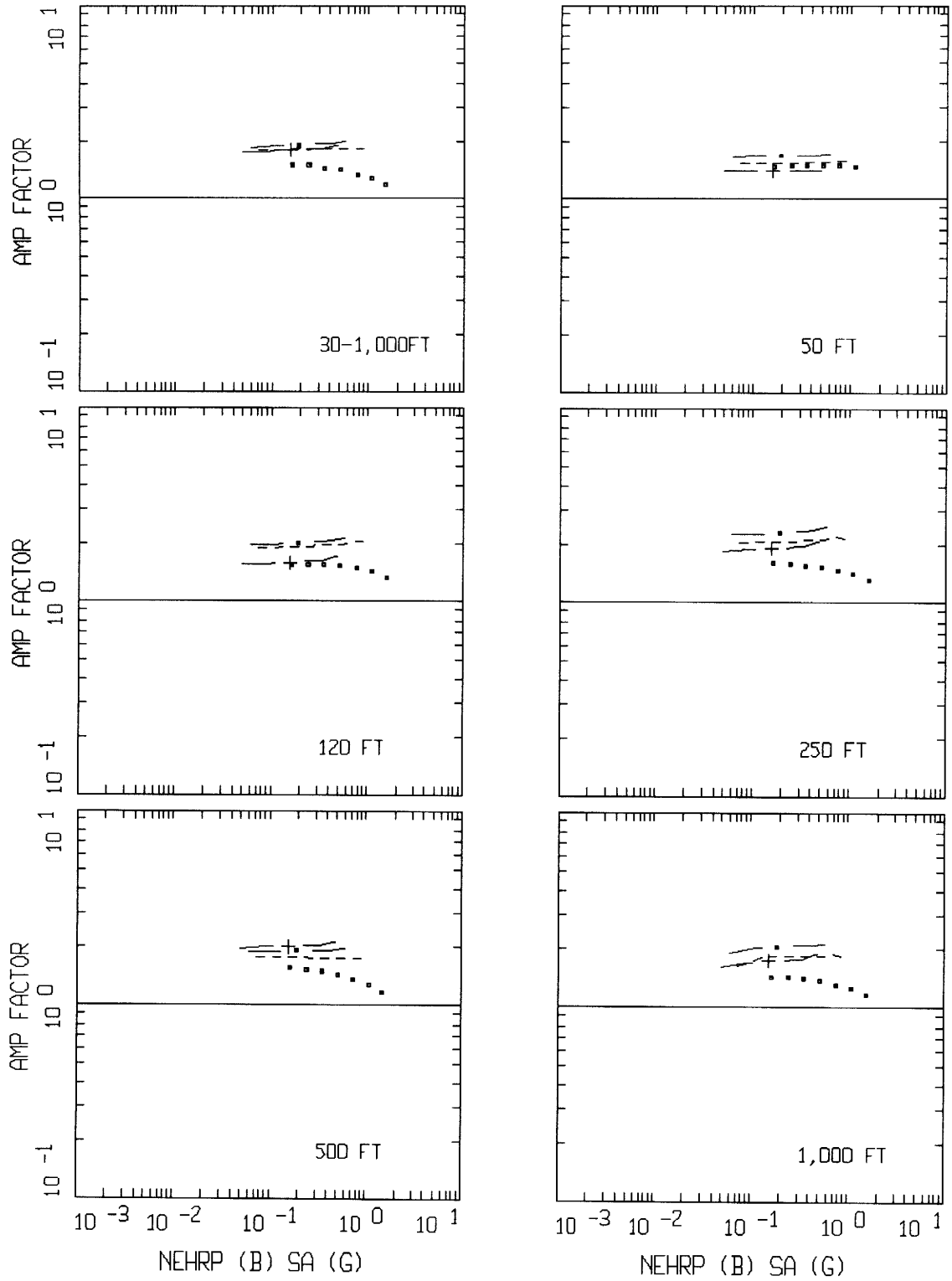
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

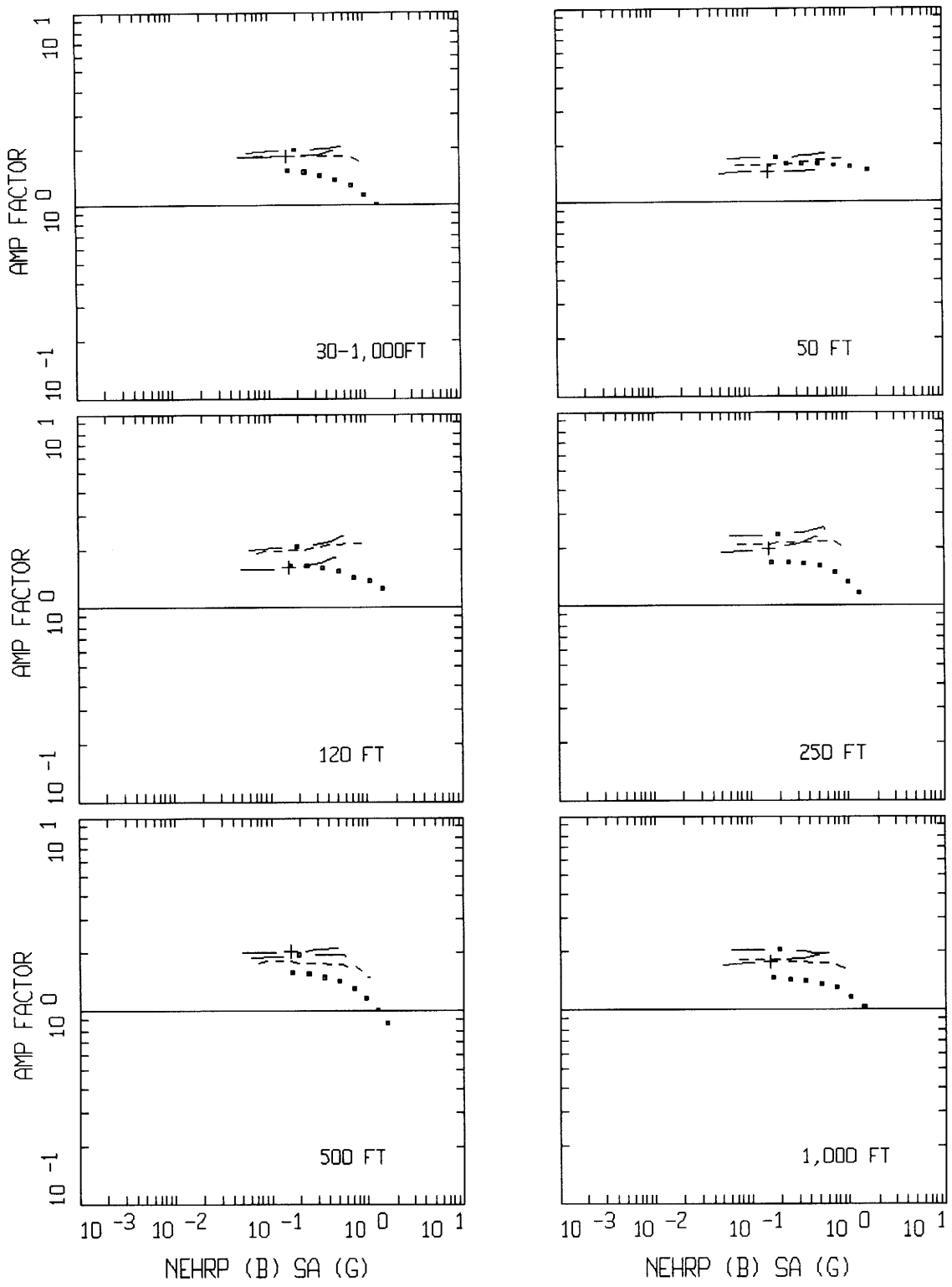
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

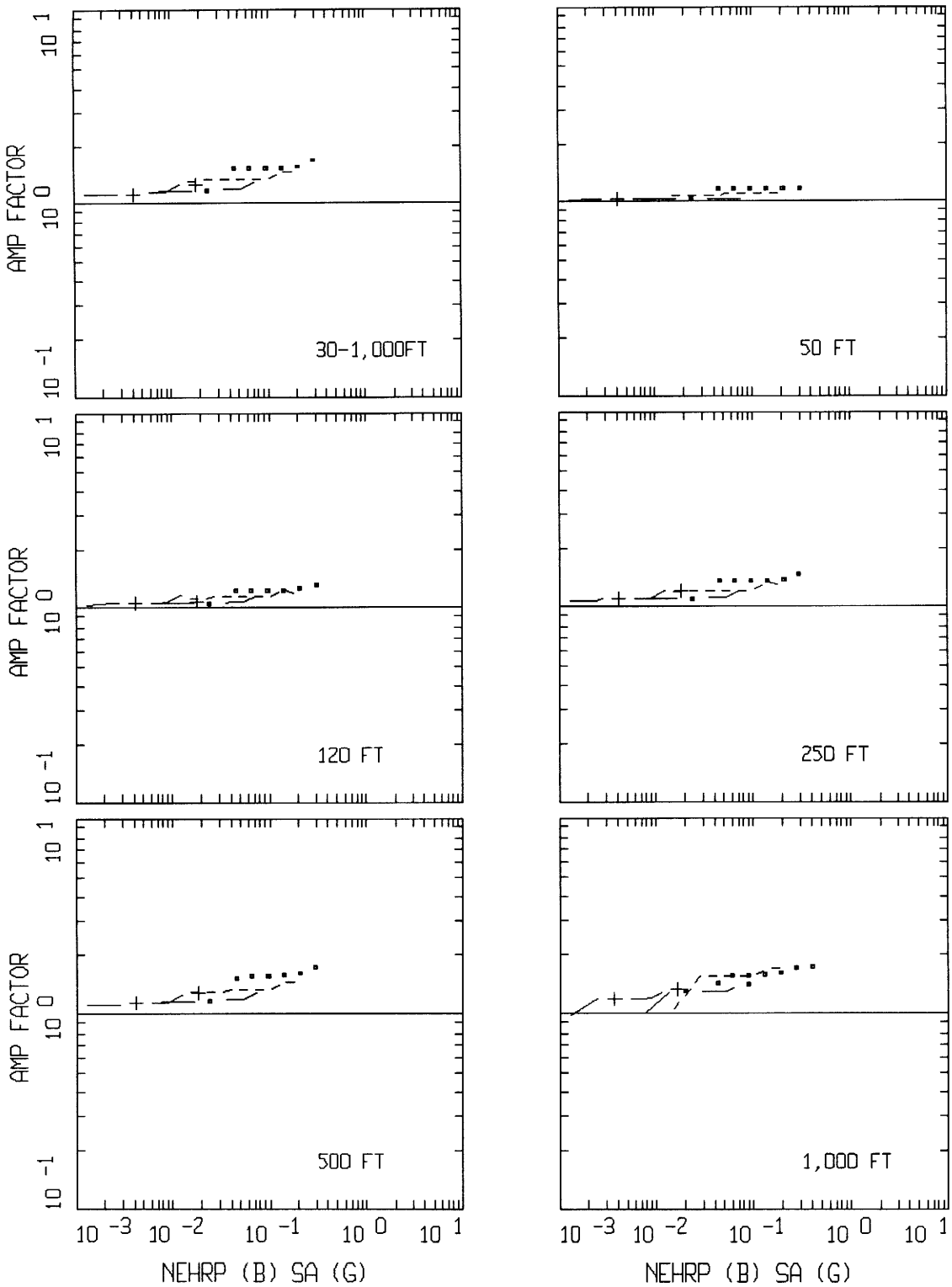
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

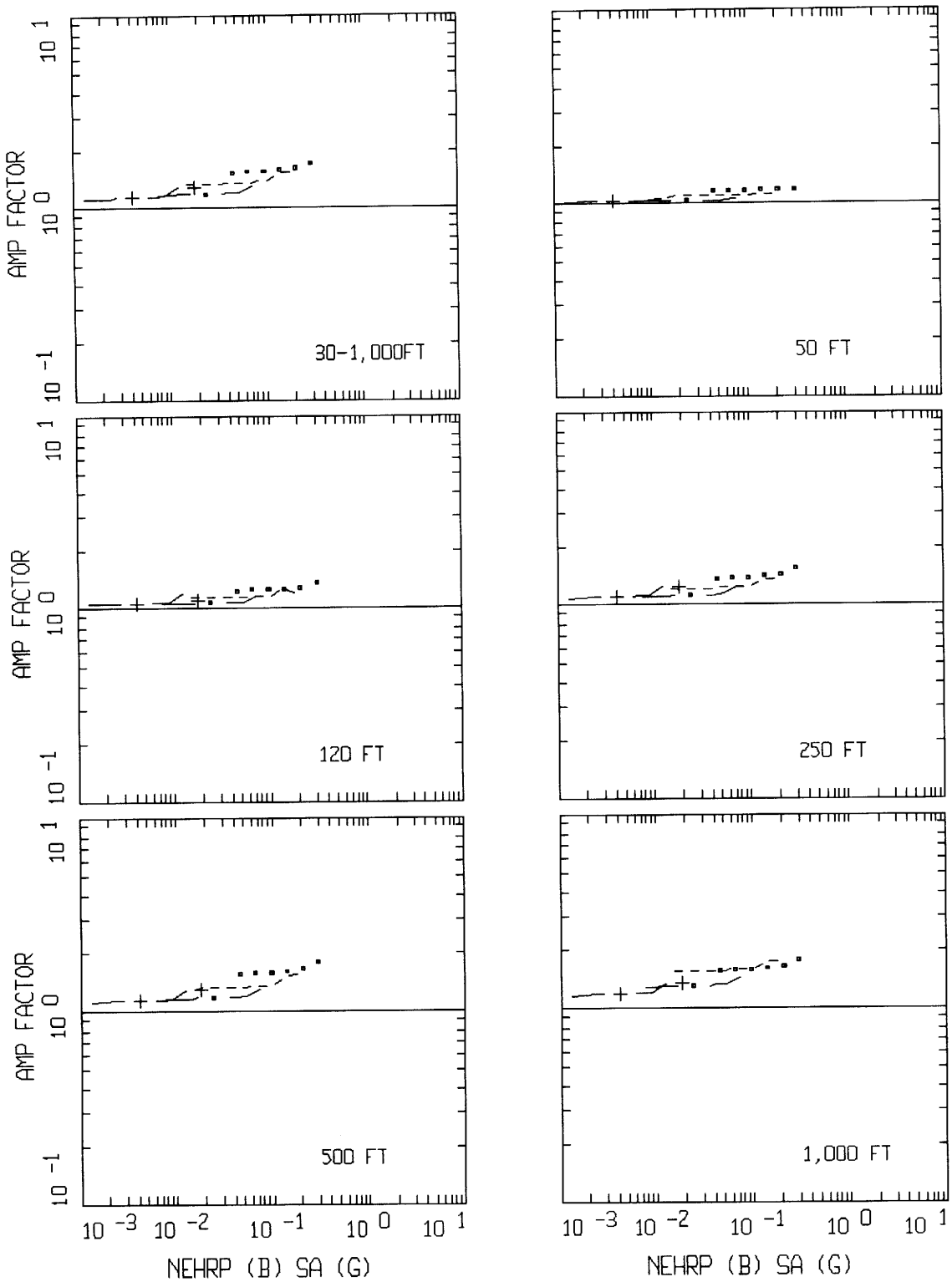
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
BNL SOIL MODEL

LEGEND

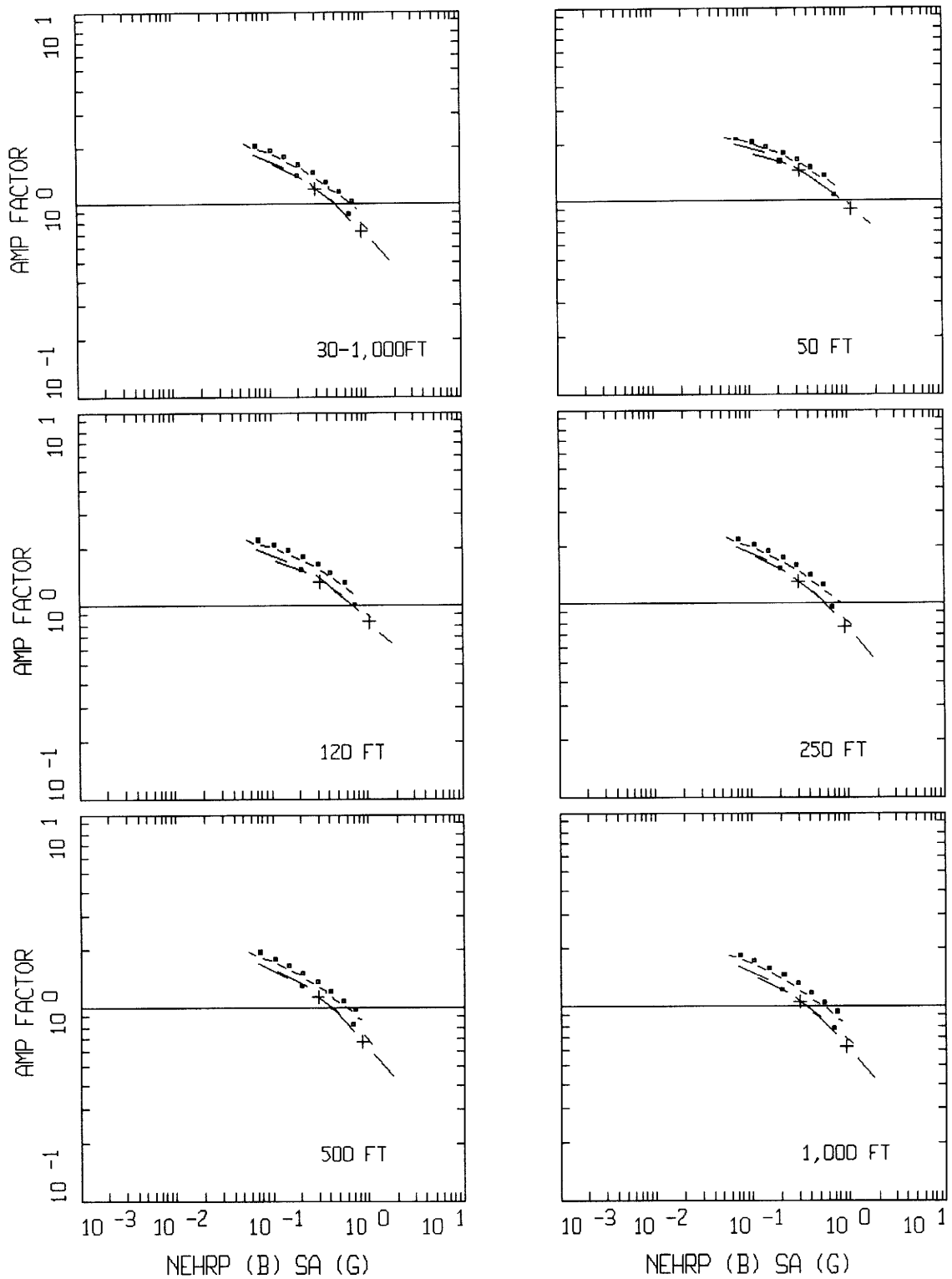
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(C) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

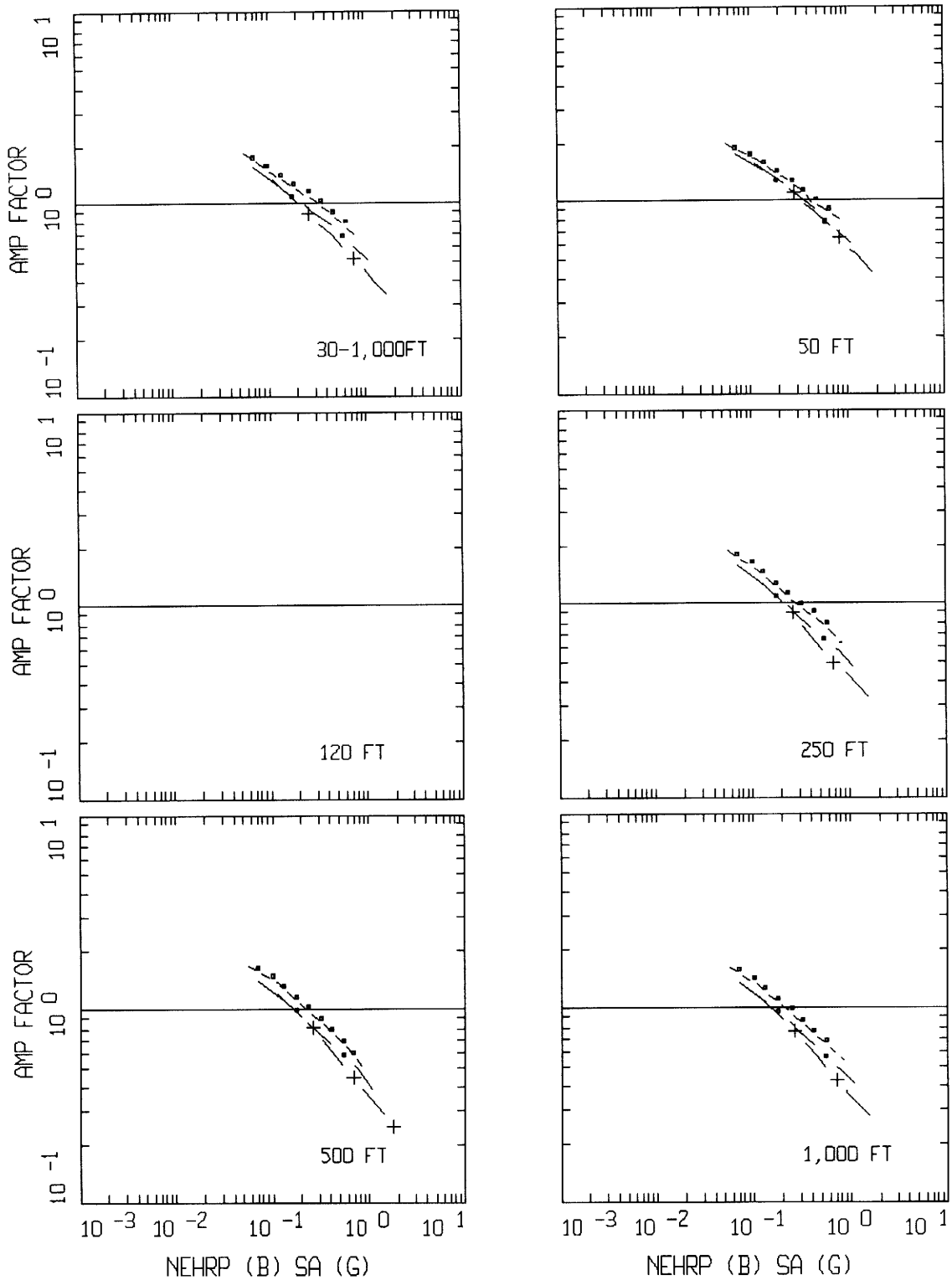
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

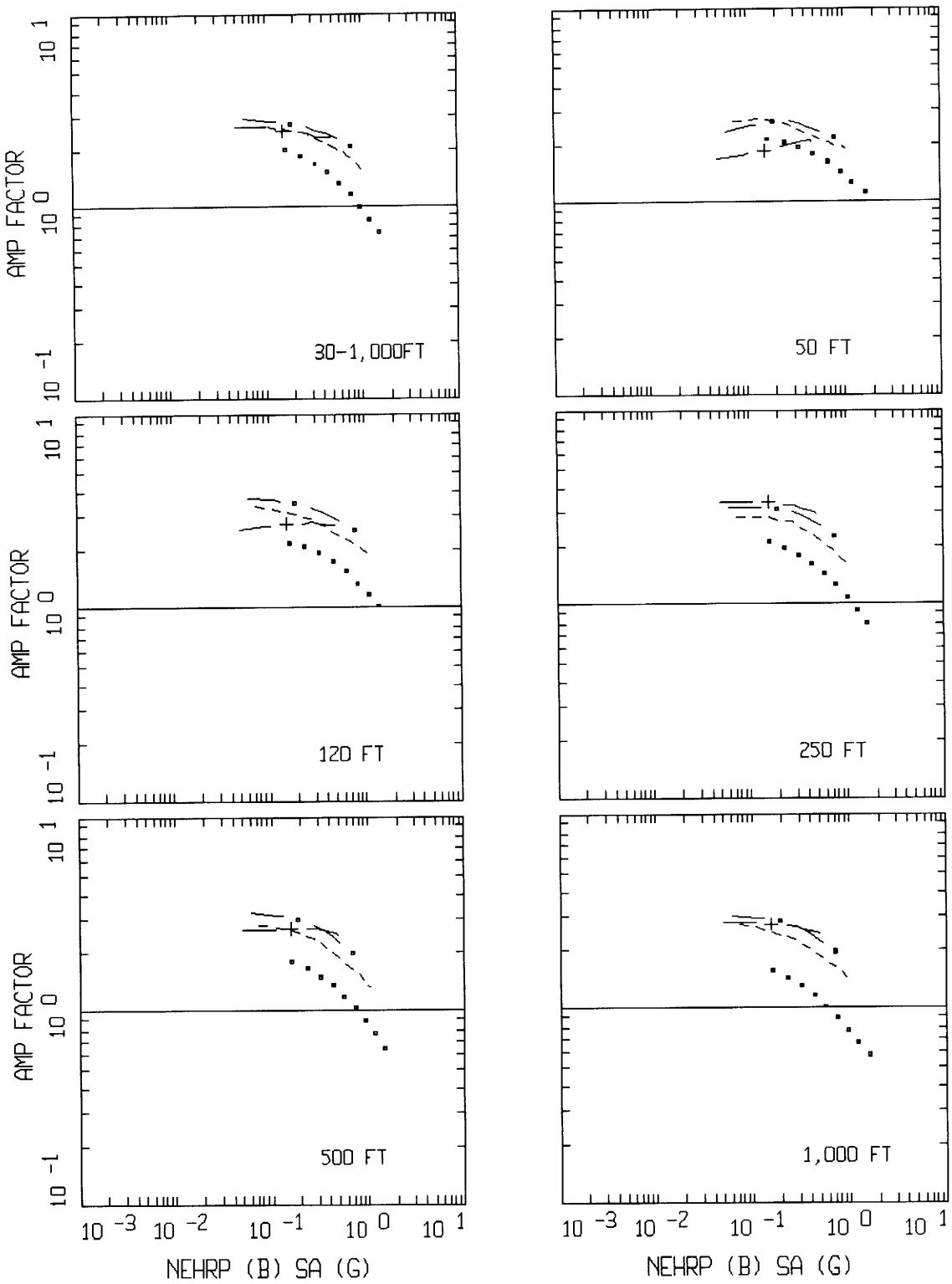
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

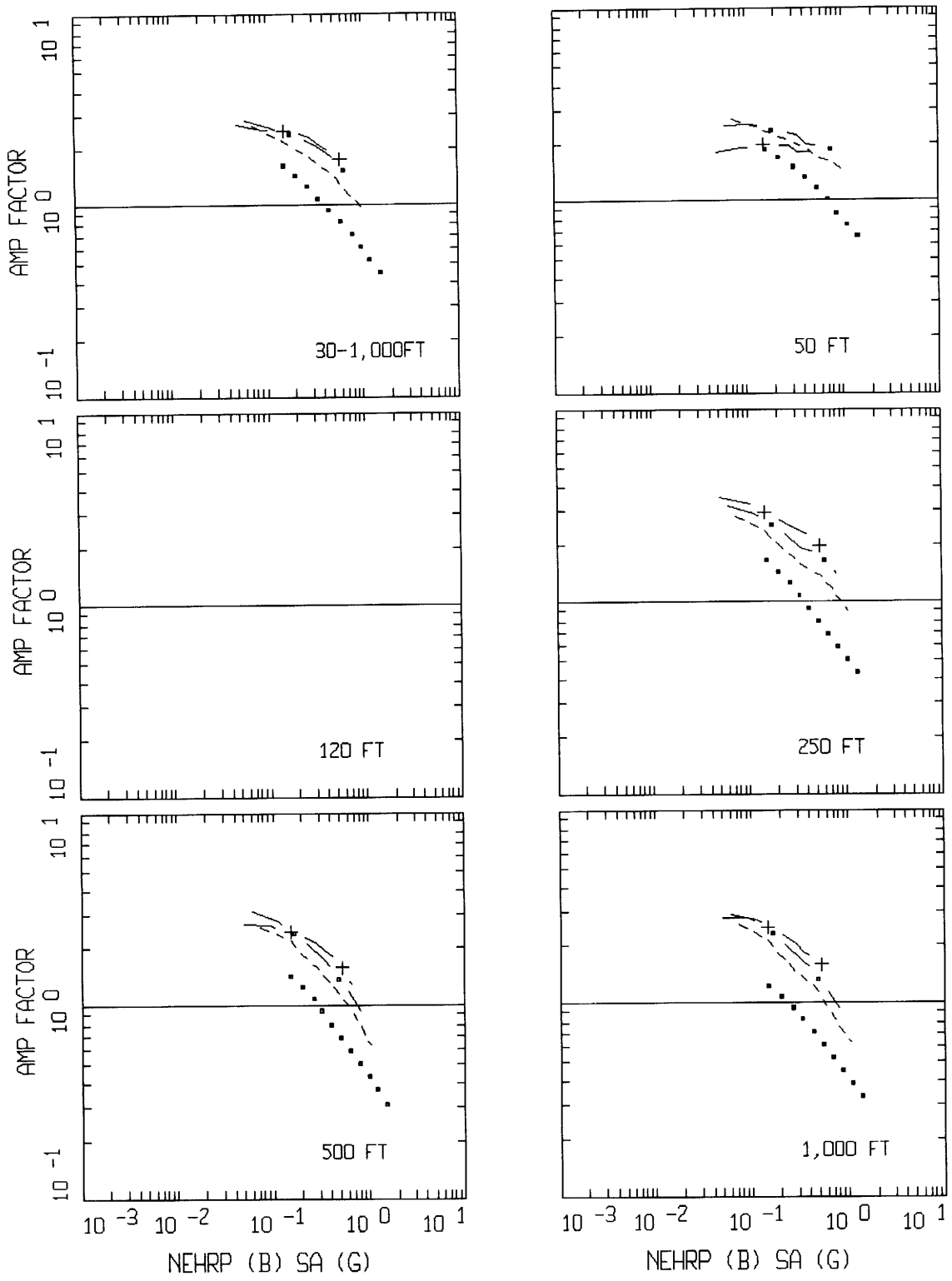
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

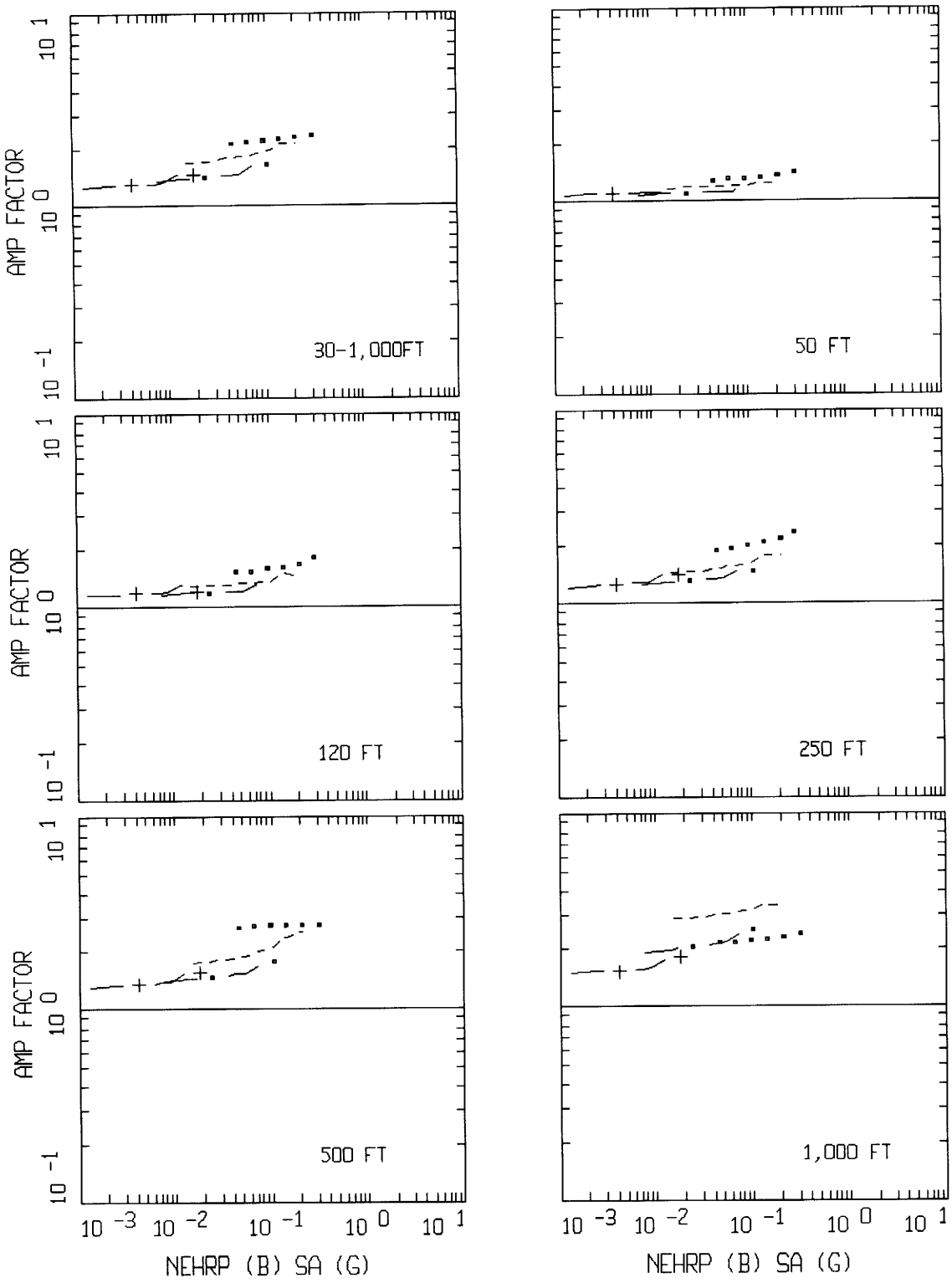
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

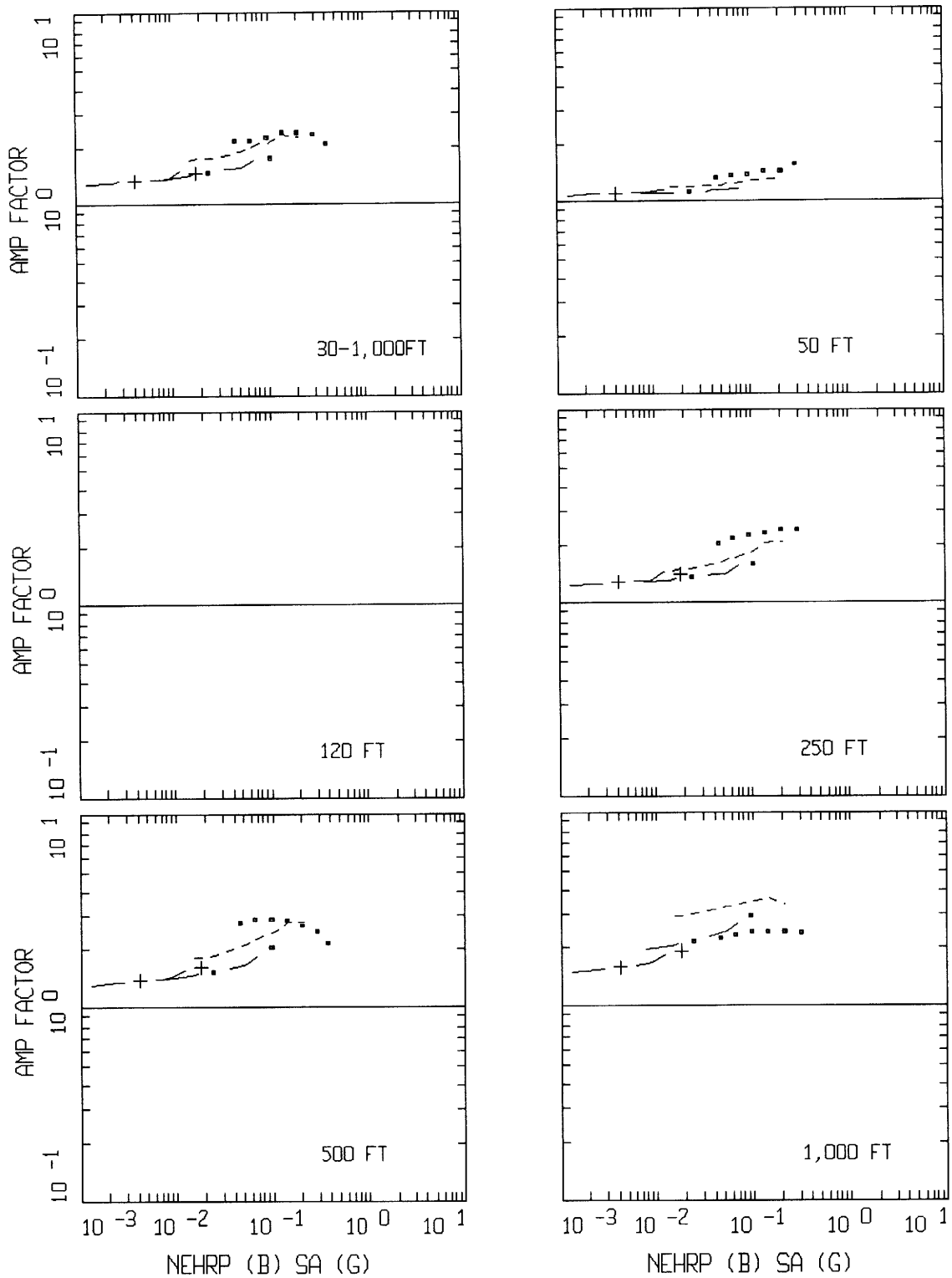
• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
BNL SOIL MODEL

LEGEND

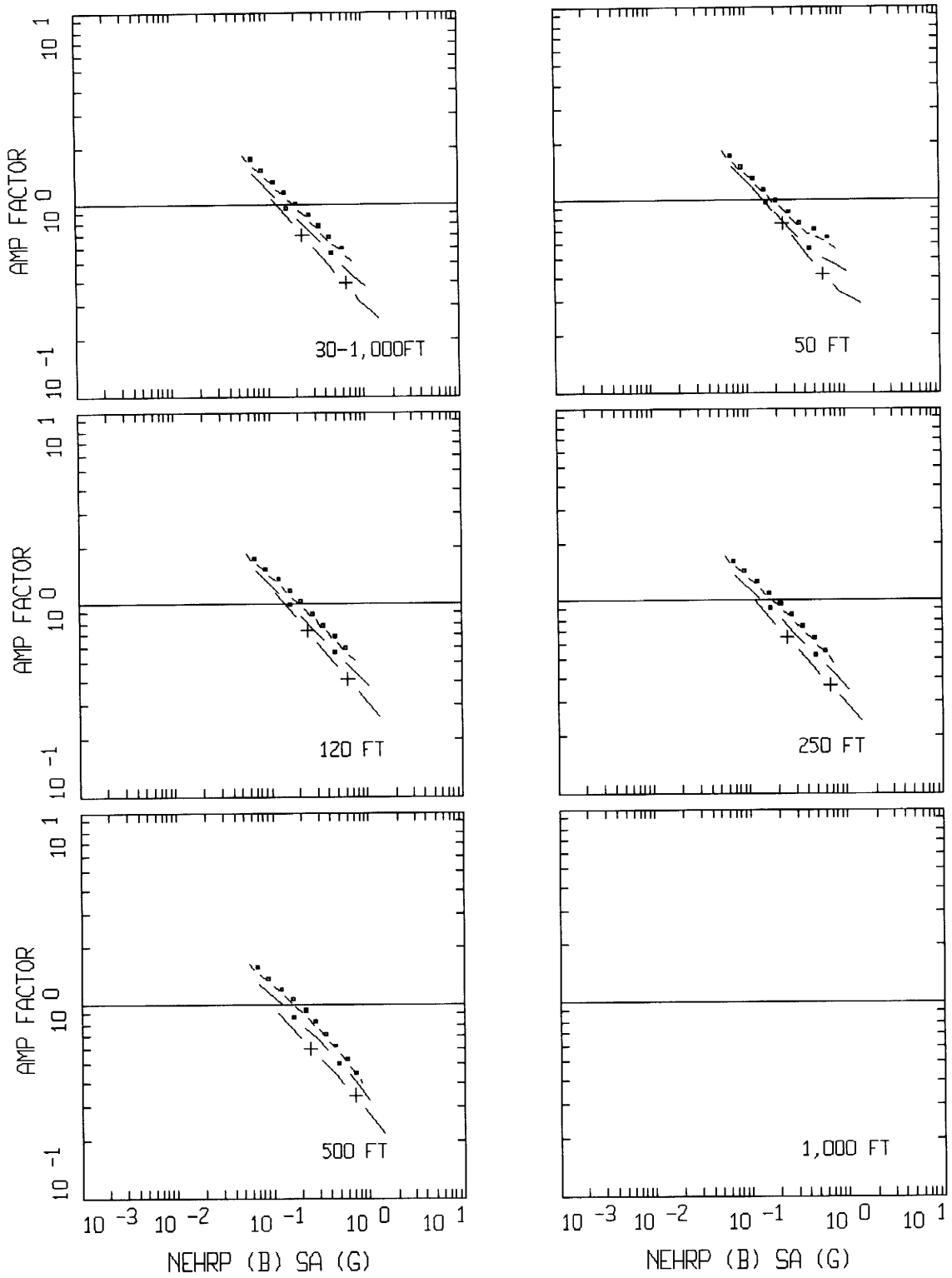
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(D) / NEHRP(B)
EPRI SOIL MODEL

LEGEND

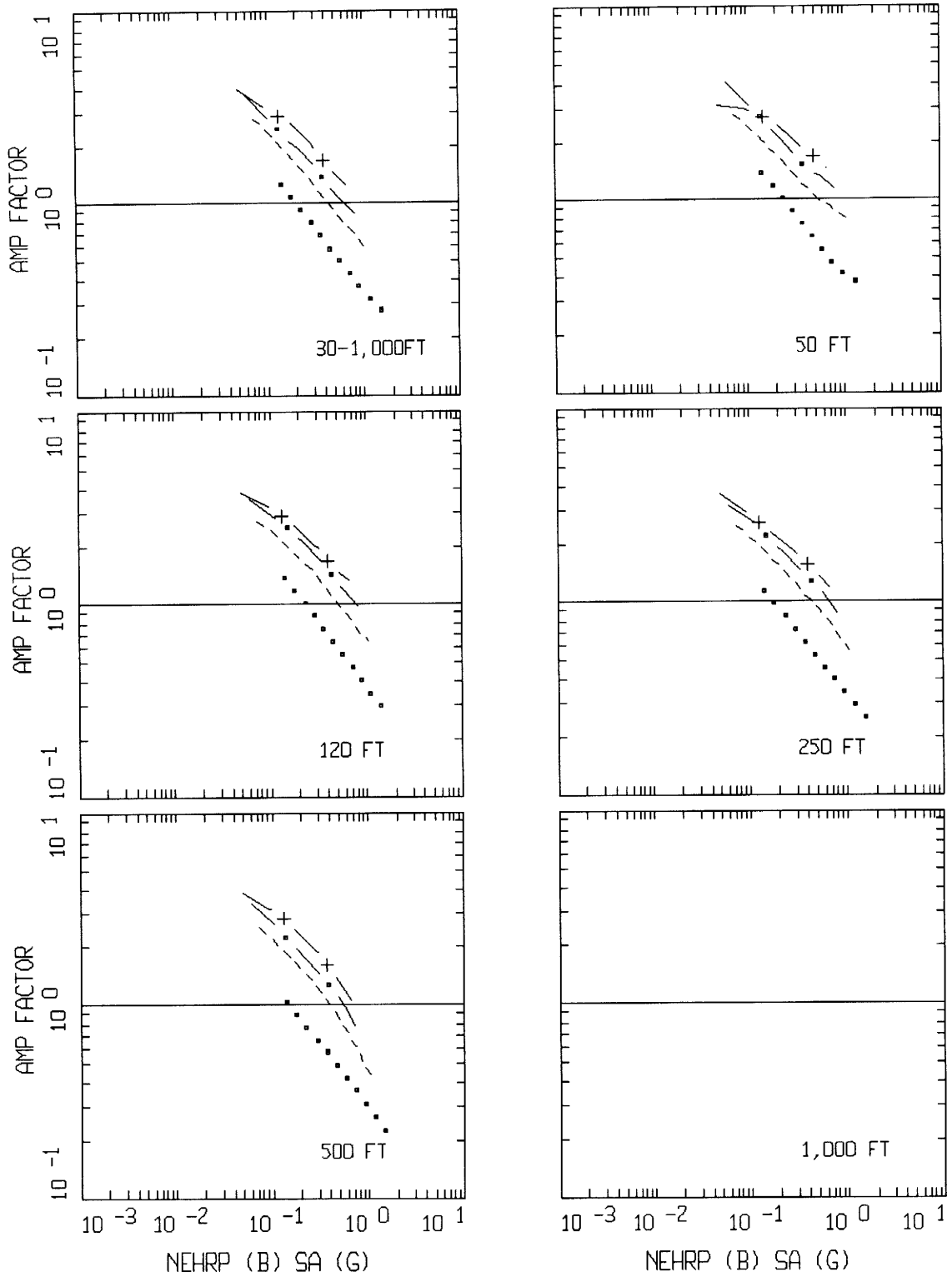
• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

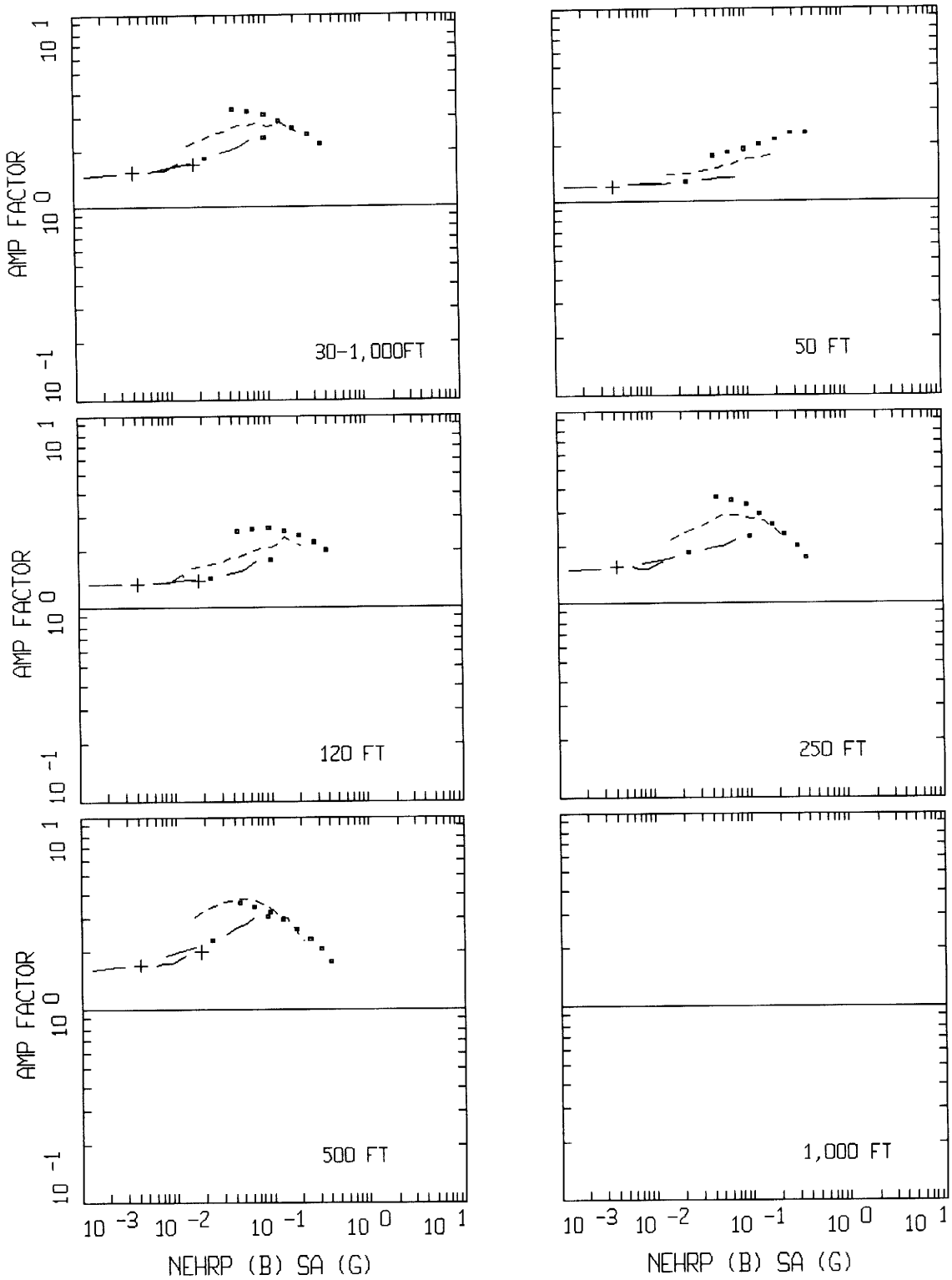
• • • •	FREQ = 100 HZ
- - - - -	FREQ = 34 HZ
— • —	FREQ = 20 HZ
— + —	FREQ = 10 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

• • • •	FREQ = 5 HZ
- - - - -	FREQ = 2 HZ
— • —	FREQ = 1.5 HZ
— + —	FREQ = 1 HZ
———	UNITY LINE



AMPLIFICATION FACTORS
NEHRP(E) / NEHRP(B)
SOIL MODEL

LEGEND

• • • •	FREQ = 0.5 HZ
- - - - -	FREQ = 0.3 HZ
— • —	FREQ = 0.2 HZ
— + —	FREQ = 0.1 HZ
———	UNITY LINE