COMPARISON OF NEAR-SITE

QUARRY BLAST CHARACTERISTICS

TO THE SEISMIC DESIGN

AT

LIMERICK GENERATING STATION

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INTRODUCTION

The effects of nearby quarry blasting on Category I structures at the Limerick Generating Station in east central Pennsylvania have been addressed. In order to identify the character and amplitude of the blast-generated seismic energy, usable blasting records have been processed and the resulting response spectra analyzed and compared to the Operating Basis Earthquake (OBE) design spectra employed for sensitive installations at the Limerick site.

BACKGROUND

The Pottstown Traprock Quarry is located on the south side of Sanatoga Road, about 200 feet north of the nearest plant property line. Operations are mining argillaceous siltstone in the vicinity of a western splay of the diabase dike exposed at the surface in the area (Figure 1). The plant site is situated to the south-southeast of the quarry on thinly bedded, competent siltstones and sandstones which dip gently (10-20 degrees) to the north, toward the quarry site. Between the quarry and the site, the north-northeast-trending Downingtown dike has been intruded along the Sanatoga fault, a system of echelon shears with brecciated and metamorphosed contacts.

Ground motion records from seven quarry blasts just north of the Limerick site were made available for this review. These blasts and attendant parameters are listed on Table 1. The recordings were made with standard instruments whose response characteristics record a trace with amplitudes directly proportional to velocity. The recordings have been made by experienced blast-monitoring engineers from Vinocon, Inc., Vibra-Tech Engineers, Inc., and, most recently, by VME-Nitro Consult, Inc. The records processed in this analysis were monitored by VME-Nitro Models E and G velocity recorders, both with flat frequency response ($\pm$3dB) from 5 to 200 Hz and a transducer natural frequency of 4.5 Hz. All measured values have been confirmed through direct contact with recording engineers in the respective firms.

It is readily apparent from inspection of Table 1 that peak velocities recorded at distances of concern are extremely low, and constitute, in most cases, vibratory ground motion which is only barely discernible above "background noise". The durations of the strongest motion are generally below one-half second, with total duration at distance not exceeding one second (Figures 2 and 3). The earlier shots (1970, 1974, and 1976) produced definitive time histories, but only with large blasts (pounds per delay period) recorded at distances less than 530 feet from the nearest shot hole (Table 1). "Pounds per delay period" represents the largest amount of explosive detonated at any one particular time. Intervals between delay periods are calculated in tenths of seconds. For the most part, the ground motions recorded at distances comparable to minimum quarry-to-Category I structure distances did not produce velocity traces of sufficient amplitude and character to allow an adequate spectral analysis. By way of example, Figure 2 shows the velocity traces recorded at 250 and 2800 feet from the 629 lb. (per delay period) quarry blast of June 24, 1970. The trace recorded at the larger distance cannot be digitized and analyzed for spectral shape and content with an appropriate degree of confidence, although peak motion can be reliably determined. The strongly characterized recording at 250 feet was not used for reasons stated below. The peak motions from all available recordings, however, have been used to determine a site-specific attenuation, as discussed later.

PROCEDURE

In order to identify and characterize the spectral content of a quarry blast which might be anticipated for the future, two of the three recordings from the February 4, 1980 shot were selected for processing. All three traces, recorded at 1850, 2820, and 3900 feet, are shown on Figure 3 and it can be seen that the trace recorded at the 3900-foot distance is unsuitable for spectral analysis. It should be emphasized that even the time histories recorded at 2820 feet are marginal with respect to the digitizing process, but are of sufficient clarity to use as a "distant" record for this analysis. It was considered more appropriate to analyze these records taken at distances which were most comparable to the distances of concern here —that is, minimum quarry-to-pump house (1850 ft) and reactor building (3300 ft) as shown on Figure 1. This would mitigate possible anomalous results inherent in the extreme distance (and source "size") scaling procedure which would be required using the stronger records from high yield blasts at the short distances (as shown for the 1970's on Table 1). Also, it is apparent that actual available blast energy (pounds of explosive per delay period) has been reduced over the years, reflecting perhaps more efficient use of explosives in smaller, multiple down-hole configurations. Therefore, even though the shot of February 4, 1980, with a maximum explosive load per delay period of 410 pounds furnishes the only data considered applicable to this analysis, it may constitute an adequate representation of spectral composition for future blasting at the distances of concern.

The velocity records for the February 4, 1980 blast were processed in the following manner. The traces of all three components of velocity (longitudinal, vertical, and transverse) were digitized at the California Institute of Technology's seismological laboratory using standard equipment employed by that lab for such analog to digital conversions. The digitized velocity time histories were then stored on disc in the PRIME computer system which is connected to the digitizer. A data tape was then prepared for use with Dames & Moore's computer system (UCS CDC 6600). The digitized records were scaled (set) to the peak values supplied by the monitoring engineers using Dames & Moore's HISPLT program developed specifically for scaling and plotting time histories in any required format. Acceleration time histories were derived through differentiation of the velocity components by the time interval of .005 seconds, allowing the analysis to adequately represent spectral characteristics up to about 50 Hertz. The acceleration time histories were input to Dames & Moore's SPECPLT program which plotted the specified response spectra for each component at values of 0.0, 0.5, 2.0, and 10.0% damping. The resulting spectra are shown on Figures 4a through 4f and, although the plots are run out to 100 Hz, we do not consider the spectra reliable above 50 Hz. This appears to be adequate for this analysis. The programs used to prepare these spectra have been properly certified and have been employed in former work where regulatory quality assurance procedures were mandated.

RESULTS

Figure 5a compares a 2% damped blast response spectrum of each of the three components of motion to the OBE design spectra employed for Category I structures at the Limerick Generating Station. These blast spectra are derived, as previously discussed, from a recording taken at the electric substation just north of the spray pond (Figure 1) at a distance of 1850 feet from the shot. This 1850-foot distance happens to correspond to the closest approach of a quarry face to the Spray Pond Pump House, as shown on Figure 1. The spectrum of each component of motion is anchored on the tripartite graph at its respective peak acceleration level which was taken from the acceleration time history computation discussed above (See Table 1). The OBE design spectra are anchored at the 7.5% of gravity (g) specified for seismic design at the Category I structures. It is seen that, except for an extremely small exceedance by the longitudinal blast component in the frequency range of about 41 to 47 Hz, the blast spectra are enveloped by the design spectra.

In the interest of providing site dependent background data and an estimate for scaling the spectra to appropriate distances, site specific attenuation functions for both velocity and acceleration were plotted and are shown on Figures 6 and 7. The maximum peak velocities (strongest component) have been plotted (Figure 6) against the ratio of the recording distance to the square root of the charge weight (lbs per delay period), a format typically employed in blast monitoring and used by Bechtel in establishing an explosive utilization curve for Limerick's on-site blasting program. The curve of Figure 6 was constructed to envelop all but one data point, and is thus considered representative of a conservative maximum peak velocity response for the subject site. Similarly, peak horizontal component accelerations were plotted using the same format based on the acceleration levels derived from processing the five velocity time histories (Table 1, last two columns). The resulting attenuation curve (Figure 7) is considered representative of site specific transmission characteristics and furnishes conservative peak acceleration levels to which the blast spectra may be anchored for comparison to the OBE design spectra.

Figure 5b displays the 2% damped blast response spectrum (from the 2820-foot recording) for each of the three components of motion superimposed on the OBE design spectra. The blast spectra are anchored at the peak acceleration level suggested by the attenuation curve of Figure 7 — about .008 g at the 3300-foot distance (from quarry to reactor building). The distance-scaled blast spectra fall well below the design spectra at all frequencies.

DISCUSSION

It is evident from inspection of Table 1 that peak velocities imposed by quarry blasting practice at distances of concern are well below those levels which are considered significant in engineering practice, and are essentially at or just above normal background "noise". There is some scatter noted in measured peak velocity and acceleration response, however, which is probably due to locally variable foundation conditions as well as source effects and variances in transmission characteristics over the site.

As previously discussed, Figure 5a has presented the spectral response of the three components which were recorded at the electric substation, and each component was anchored, on the high frequency end, at the peak acceleration level calculated for that particular component. However, there may be differences in the energy transmission characteristics and near-surface response between the recorded quarry-to-electric substation travel path and the postulated nearest approach of the quarry to the pumphouse (Figure 1), even though the 1850-foot distance is common to both. Also, inspection of Table 1 (Columns 4 through 8) discloses that there is apparently no preferred component (orientation) for the maximum amplitudes recorded under the conditions existing at the recording sites. For these reasons, it may be more diagnostic of average site conditions to anchor the blast spectra on Figure 5a at the conservative acceleration level suggested (for the 410-lb. shot at 1850 feet) by the site specific attenuation curve of Figure 7. If each blast component spectrum were adjusted (translated vertically on the tripartite graph) to this 2% g level, the small exceedence of the design spectra by the longitudinal blast spectra near 40-45 Hz would be essentially nullified. The spectra for the other two components would be raised somewhat but would not significantly exceed the design envelope.

Aside from the expected attenuation effects of geometric spreading and material damping, "attenuation" of motion can be simulated by the "tau" effect — the local alteration of motion by the finite size of a particular foundation, particularly in the high frequency portion of the spectra. Thus, the effects of future blasting on completed, operational structures at the plant site may be somewhat different than suggested by the current monitoring program, and may result in even lower amplitudes at frequencies of concern.

In summary, based on a review of all the available blast records, it can be concluded that quarry blasting has generated velocities whose peak amplitudes are well below accepted damage thresholds at distances of concern. Moreover, the spectral response for calculated acceleration levels from quarry blasting utilizing about 410 pounds of explosive per delay period is essentially enveloped at critical frequencies by the OBE design spectra for sensitive structures at the Limerick Generating Station.

TABLE 1

QUARRY BLAST DATA

Date	Maximum lbs/delay	Recording Distance (ft)*	Measured Peak Velocity (in/sec)			Peak Horizontal Acceleration (g) (from computed acceleration time history)	
			Long.	Vertical	Trans.	Long.	Trans.
6/24/70	629	250	1.90	1.50	1.60	.732	.544
		2800	.02	.02	.03	—	—
9/4/74	694	500	.56	.67	.57	.132	.137
4/8/76	668	527	.28	.19	.32	.117	.132
2/4/80	410	1850	.09	.04	.06	.023	.017
		2820 (CT)	.03	.02	.03	.010	.009
		3900 (RB)	.02	.02	.02	—	—
4/3/80	435	2490 (PH)	.01	.01	.01	—	—
		2930 (CT)	.02	.01	.01	—	—
		3940 (RB)	.01	.01	.01	—	—
5/8/80	325	2410 (PH)	.03	.03	.03	—	—
		2850 (CT)	.02	.02	.03	—	—
		3860 (RB)	.02	.02	.02	—	—
5/29/80	336	2430 (PH)	.02	.02	.02	—	—
		2870 (CT)	.02	.03	.03	—	—
		3880 (RB)	.01	.02	.02	—	—

* PH - Pumphouse
CT - Cooling Tower
RB - Reactor Building

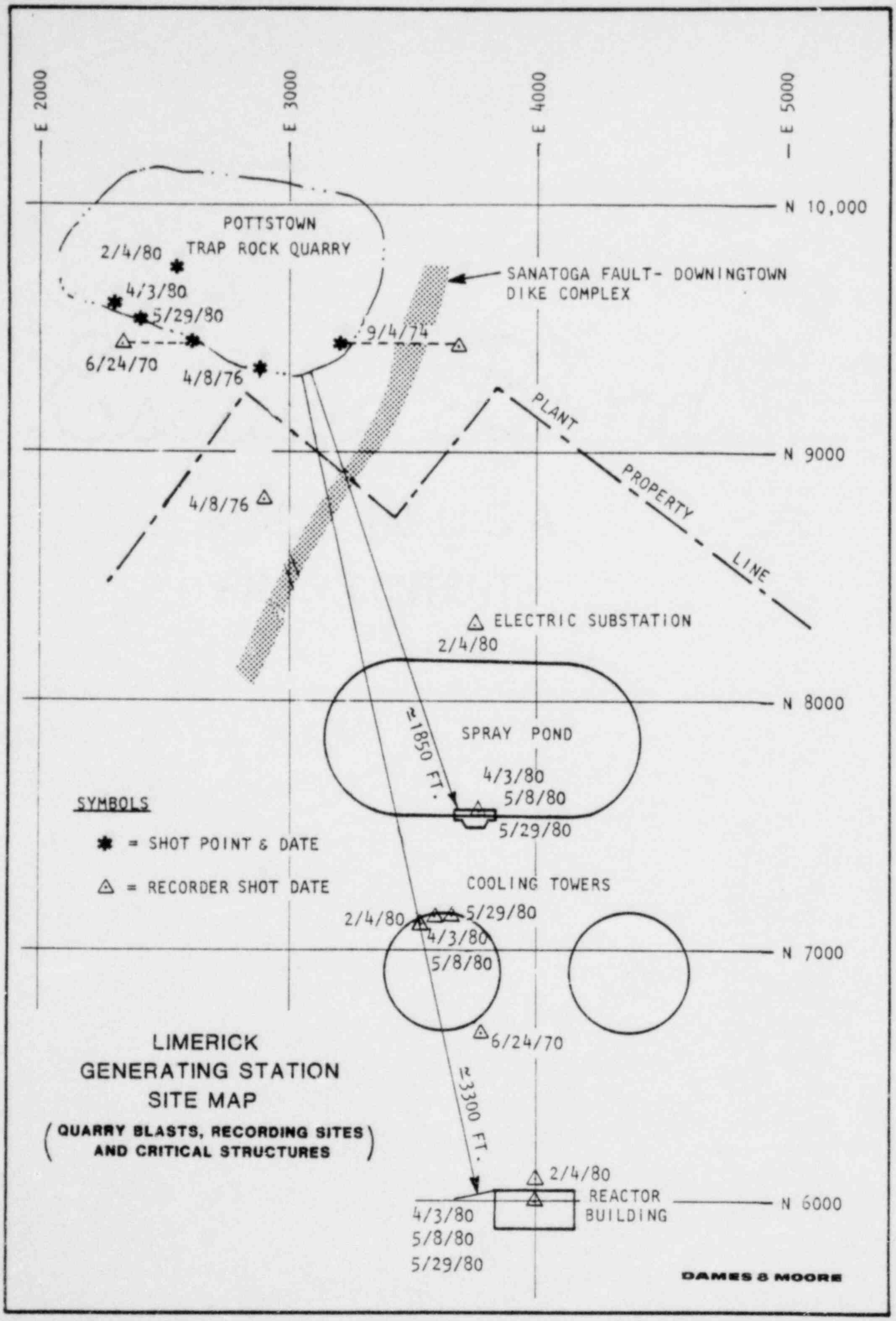
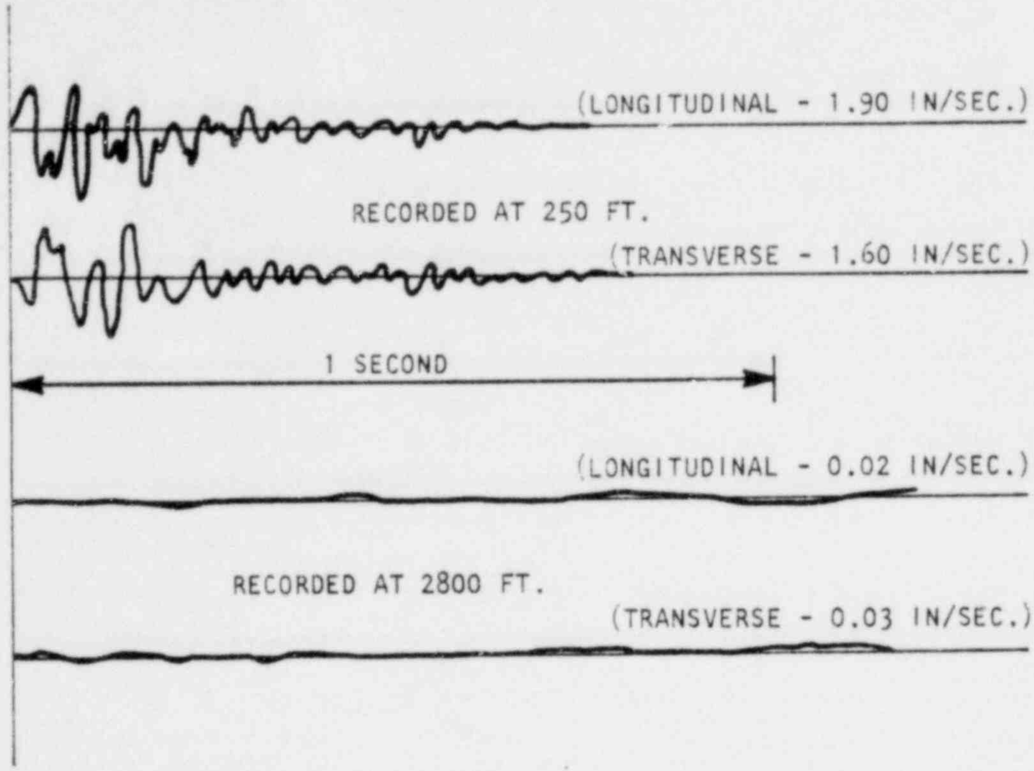

E 2000
E 3000
E 4000
E 5000
N 10,000
N 9000
N 8000
N 7000
N 6000
POTTSTOWN
TRAP ROCK QUARRY
2/4/80
4/3/80
5/29/80
6/24/70
4/8/76
9/4/74
SANATOGA FAULT- DOWNINGTOWN
DIKE COMPLEX
PLANT
PROPERTY
LINE
4/8/76
ELECTRIC SUBSTATION
2/4/80
SPRAY POND
≅1850 FT.
4/3/80
5/8/80
5/29/80
SYMBOLS
= SHOT POINT & DATE
= RECORDER SHOT DATE
COOLING TOWERS
2/4/80
5/29/80
4/3/80
5/8/80
6/24/70
≅3300 FT.
2/4/80
REACTOR
BUILDING
4/3/80
5/8/80
5/29/80
LIMERICK
GENERATING STATION
SITE MAP
(QUARRY BLASTS, RECORDING SITES
AND CRITICAL STRUCTURES)
DAMES & MOORE

FIGURE 1



RECORDED AND INTERPRETED BY:

VIBRA-TECH ENGINEERS, INC.
VIBRA-LOG SEISMOGRAPH, SPRENGNETHER VS-1100
PERIOD = 0.5 SEC.
NO. 178 AT 250 FT.
NO. 151 AT 2800 FT.

QUARRY BLAST OF JUNE 24,1970

RECORDED 250 FT. AND 2800 FT. FROM BLAST WITH MAXIMUM EXPLOSIVE/DELAY PERIOD OF 629 LBS.

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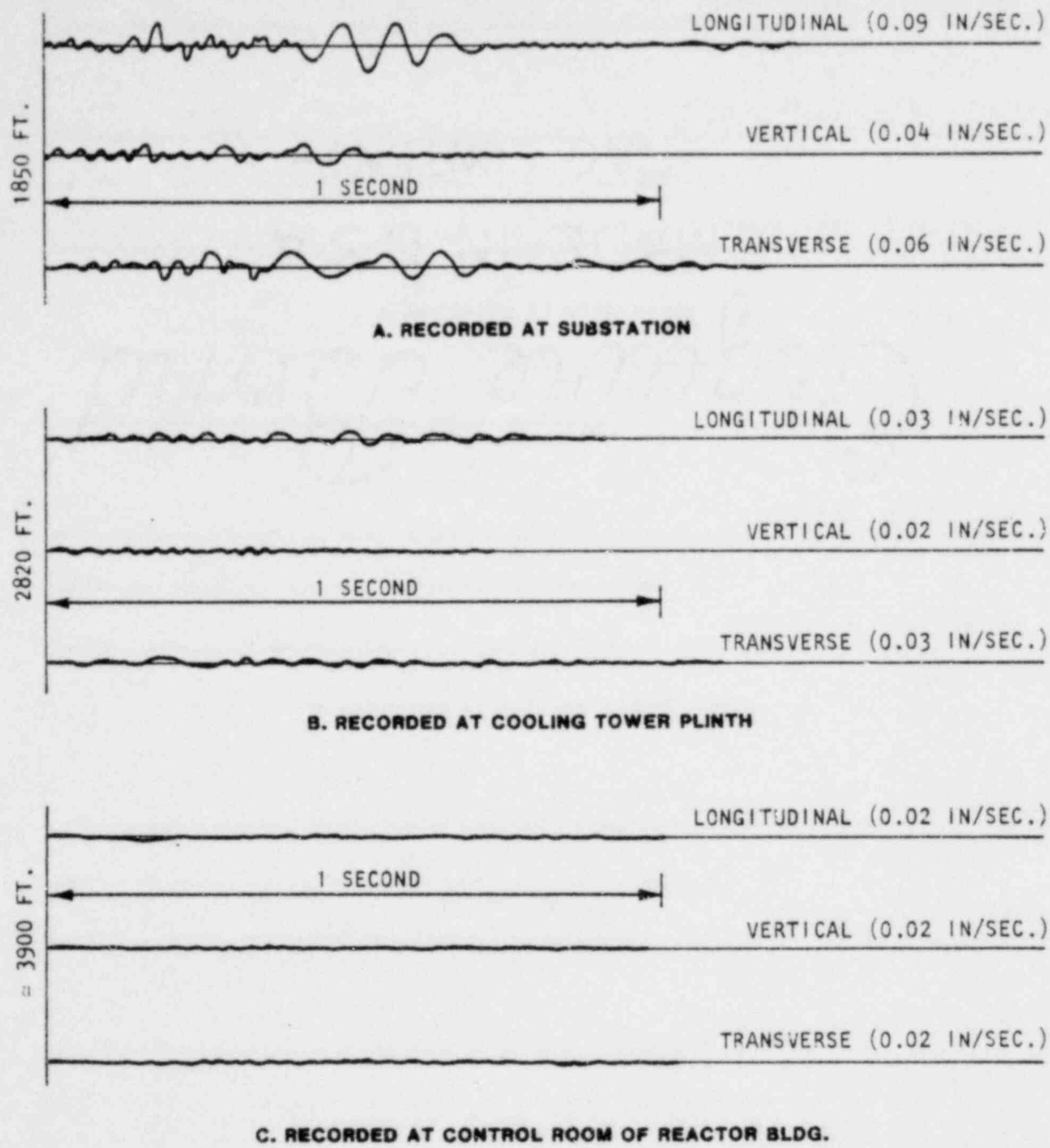
FIGURE 2



RECORDED AND INTERPRETED BY
VME-NITRO CONSULT, INC.

INSTRUMENTS: VME VELOCITY RECORDERS,
MODELS E & G

QUARRY BLAST OF FEBRUARY 4,1980

MAXIMUM EXPLOSIVE / DELAY PERIOD - 410 LBS

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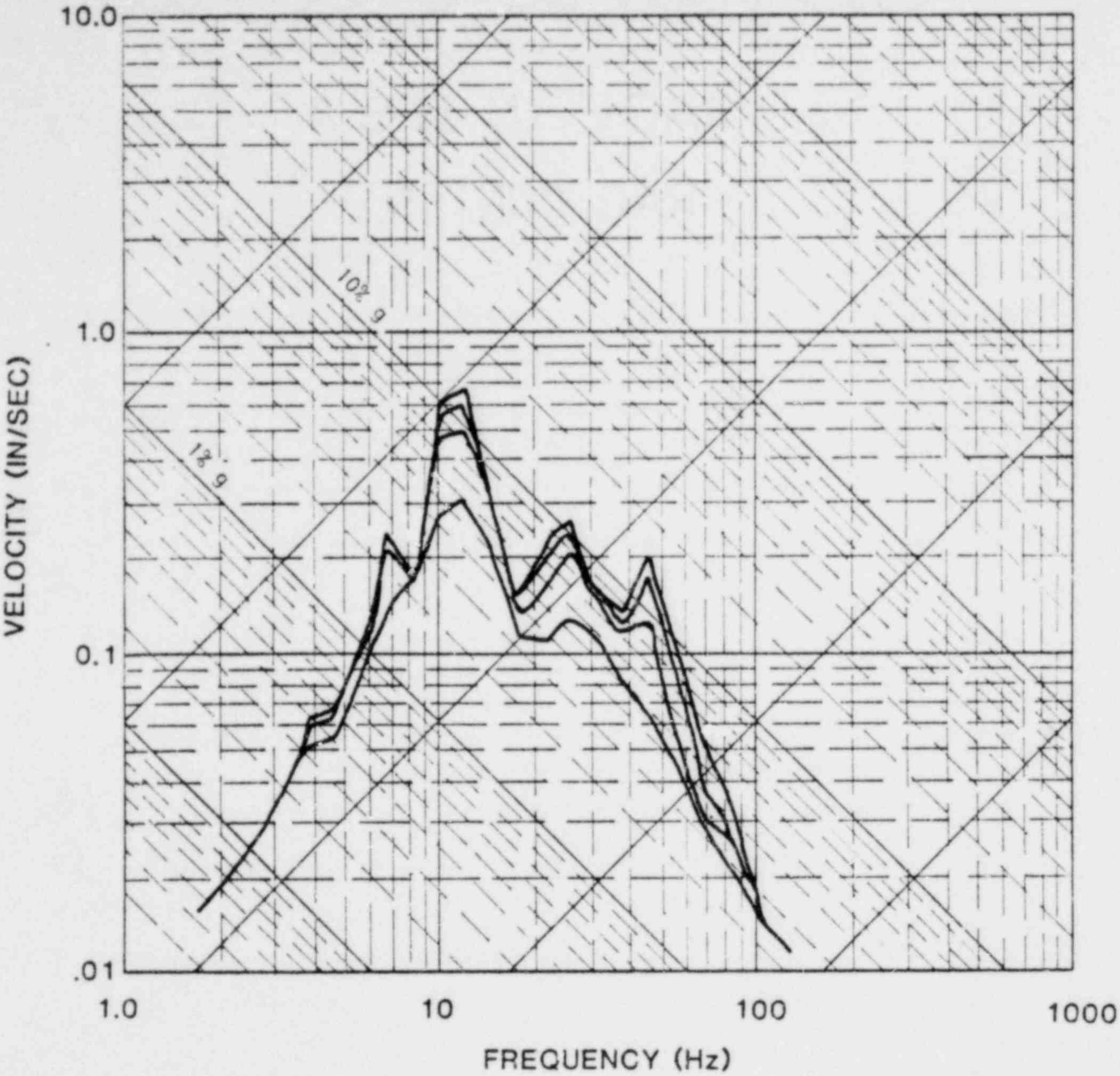
FIGURE 3



QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST 2/4/80

RECORDING SITE ELECTRIC SUBSTATION

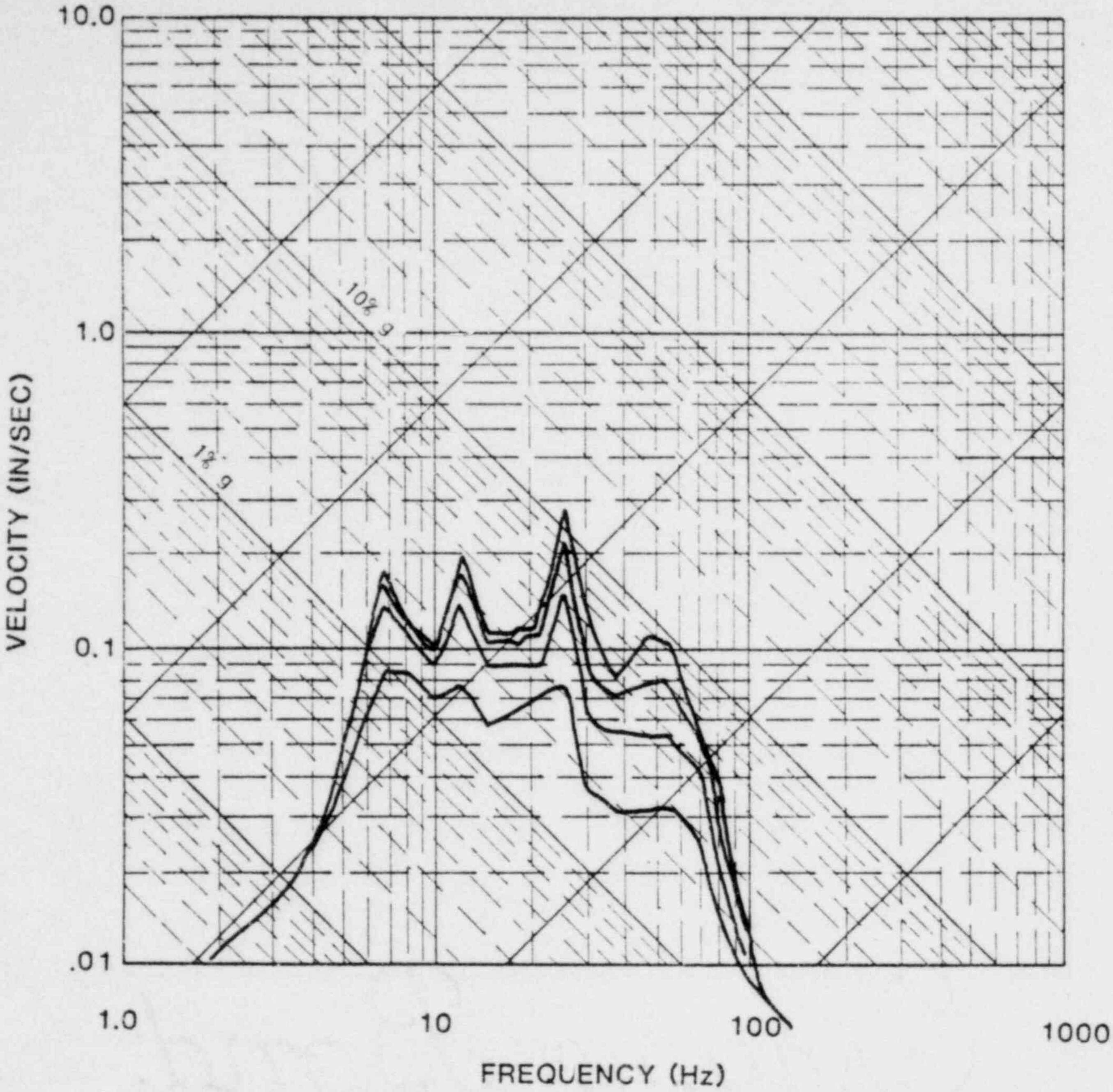
RECORDING DISTANCE 1850 FEET

MAXIMUM CHARGE/DELAY 410 LBS.

COMPONENT OF MOTION LONGITUDINAL

MEASURED PEAK VELOCITY .09 IN/SEC

FIGURE 4a

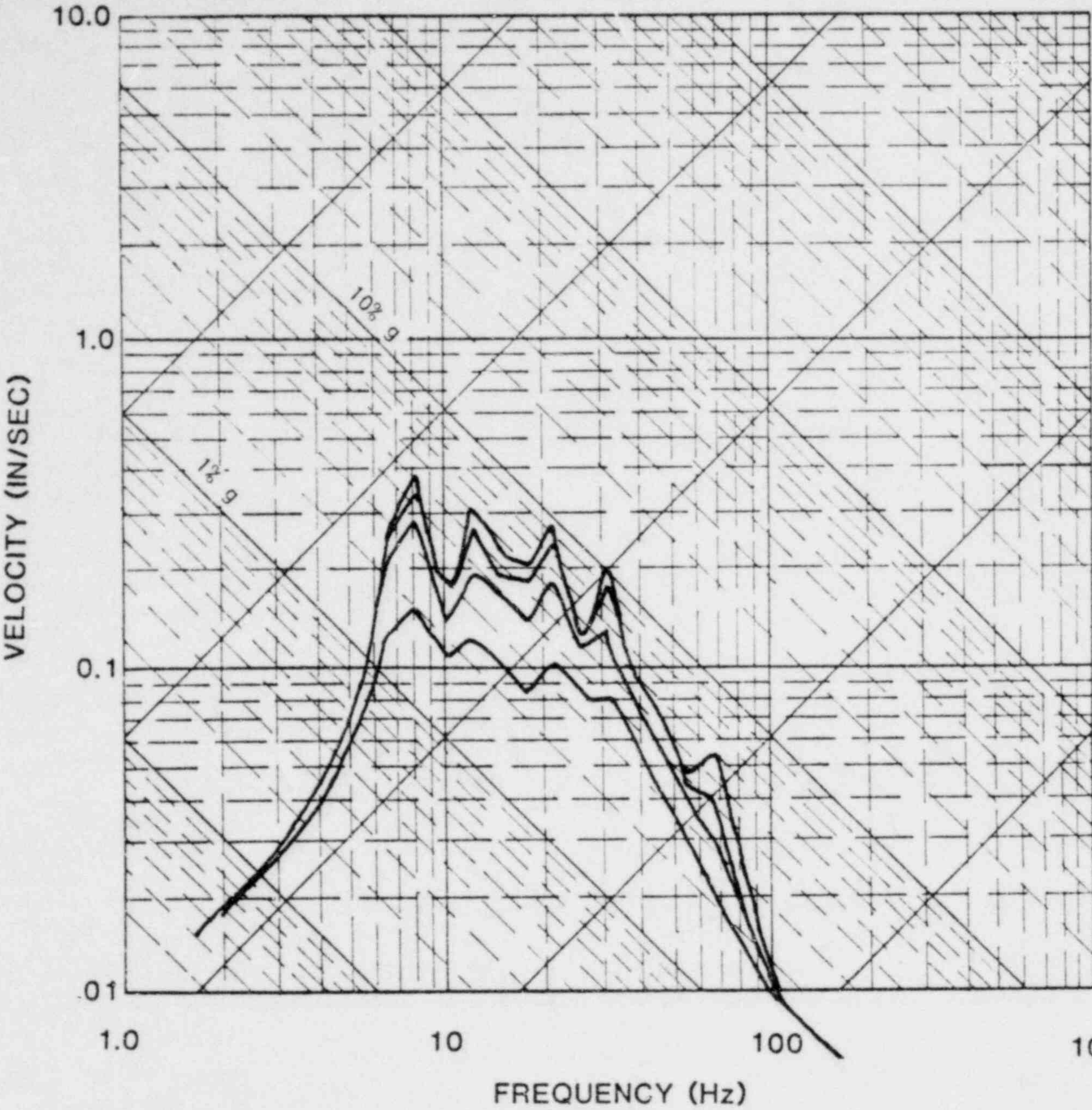


QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST	2/4/80
RECORDING SITE	ELECTRIC SUBSTATION
RECORDING DISTANCE	1850 FEET
MAXIMUM CHARGE/DELAY	410 LBS.
COMPONENT OF MOTION	VERTICAL
MEASURED PEAK VELOCITY	.04 IN/SEC

FIGURE 4b



QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST 2/4/80

RECORDING SITE ELECTRIC SUBSTATION

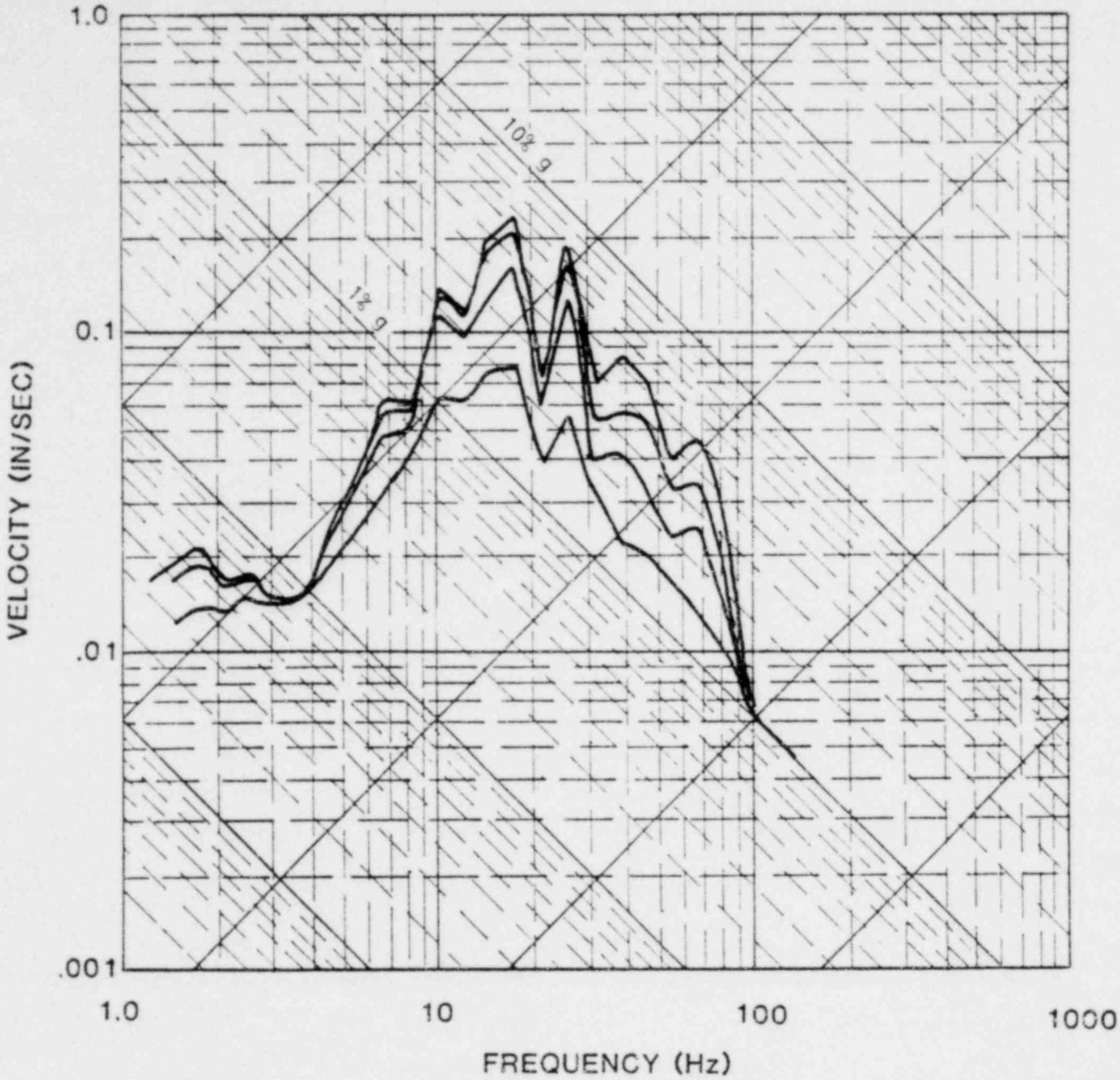
RECORDING DISTANCE 1850 FEET

MAXIMUM CHARGE/DELAY 410 LBS.

COMPONENT OF MOTION TRANSVERSE

MEASURED PEAK VELOCITY .06 IN/

FIGURE 4c



QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST 2/4/80

RECORDING SITE COOLING TOWER #1 (PLINTH #20)

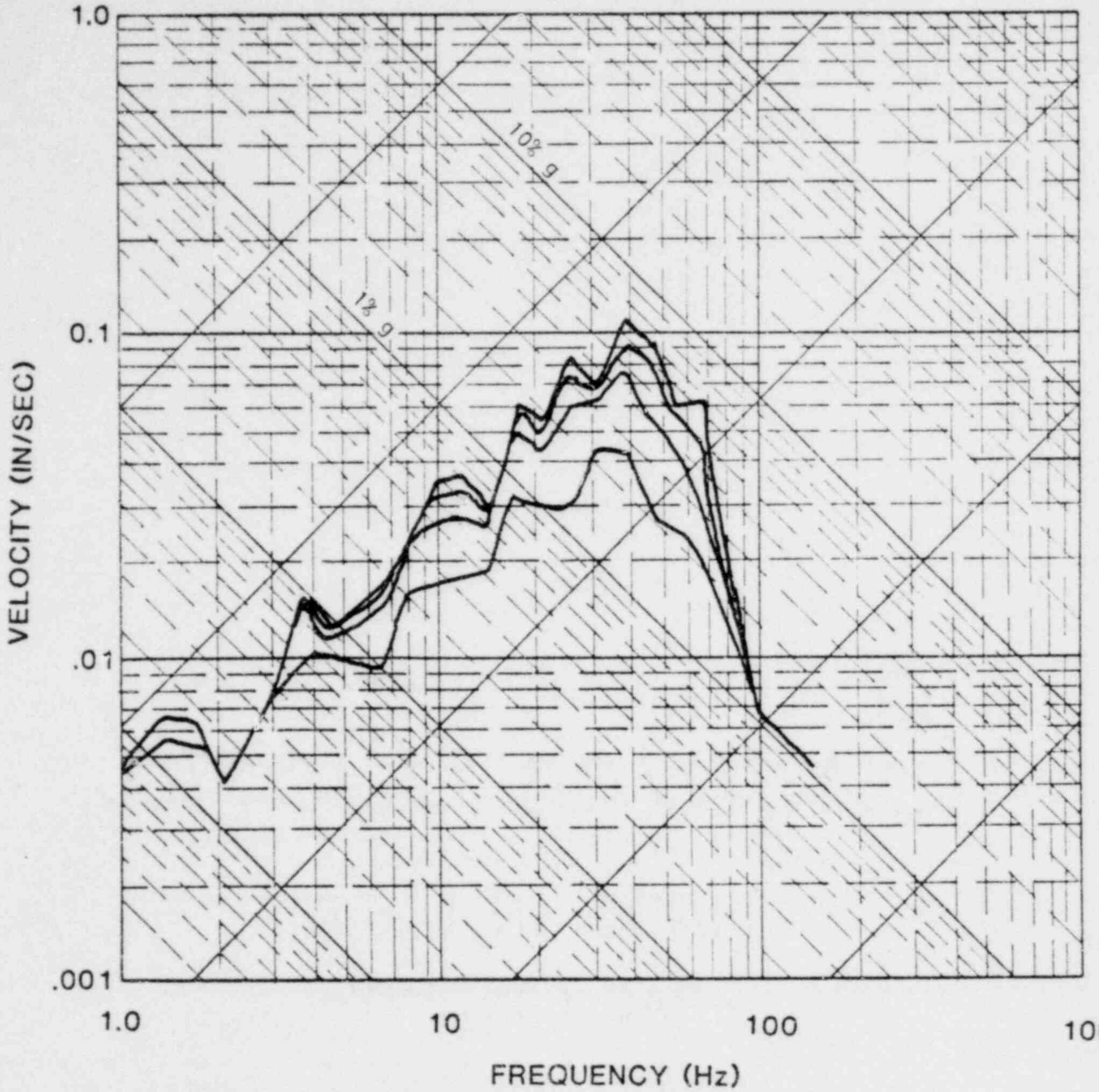
RECORDING DISTANCE 2820 FEET

MAXIMUM CHARGE/DELAY 410 LBS.

COMPONENT OF MOTION LONGITUDINAL

MEASURED PEAK VELOCITY .03 IN/SEC

FIGURE 4d



QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST 2/4/80

RECORDING SITE COOLING TOWER #1 (PLINTH #20)

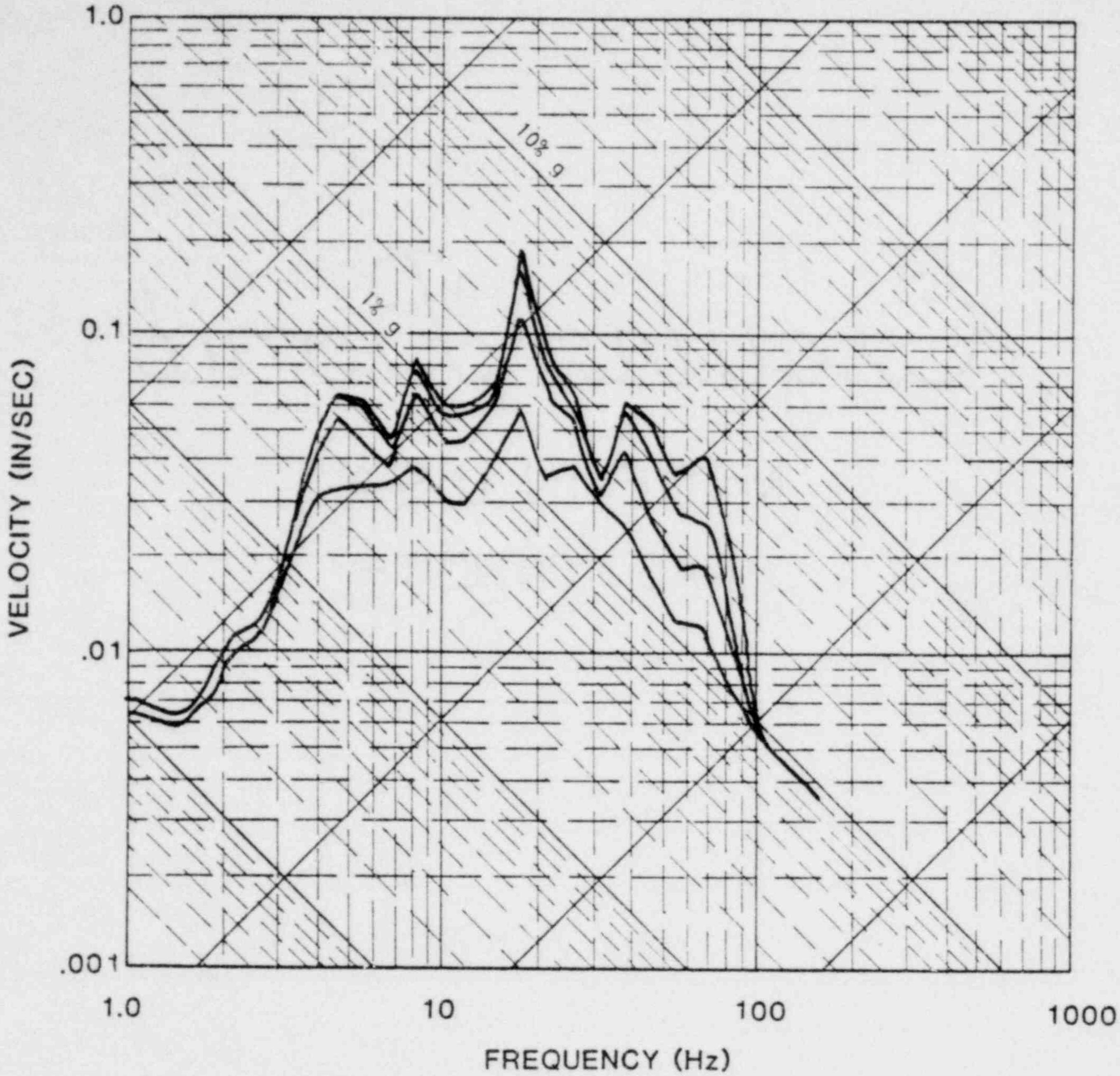
RECORDING DISTANCE 2820 FEET

MAXIMUM CHARGE/DELAY 410 LBS.

COMPONENT OF MOTION VERTICAL

MEASURED PEAK VELOCITY .02 IN/SEC

FIGURE 4e



QUARRY BLAST RESPONSE SPECTRA

(0.0,0.5,2.0 AND 10.0 PERCENT DAMPING)

DATE OF BLAST 2/4/80

RECORDING SITE COOLING TOWER #1 (PLINTH #20)

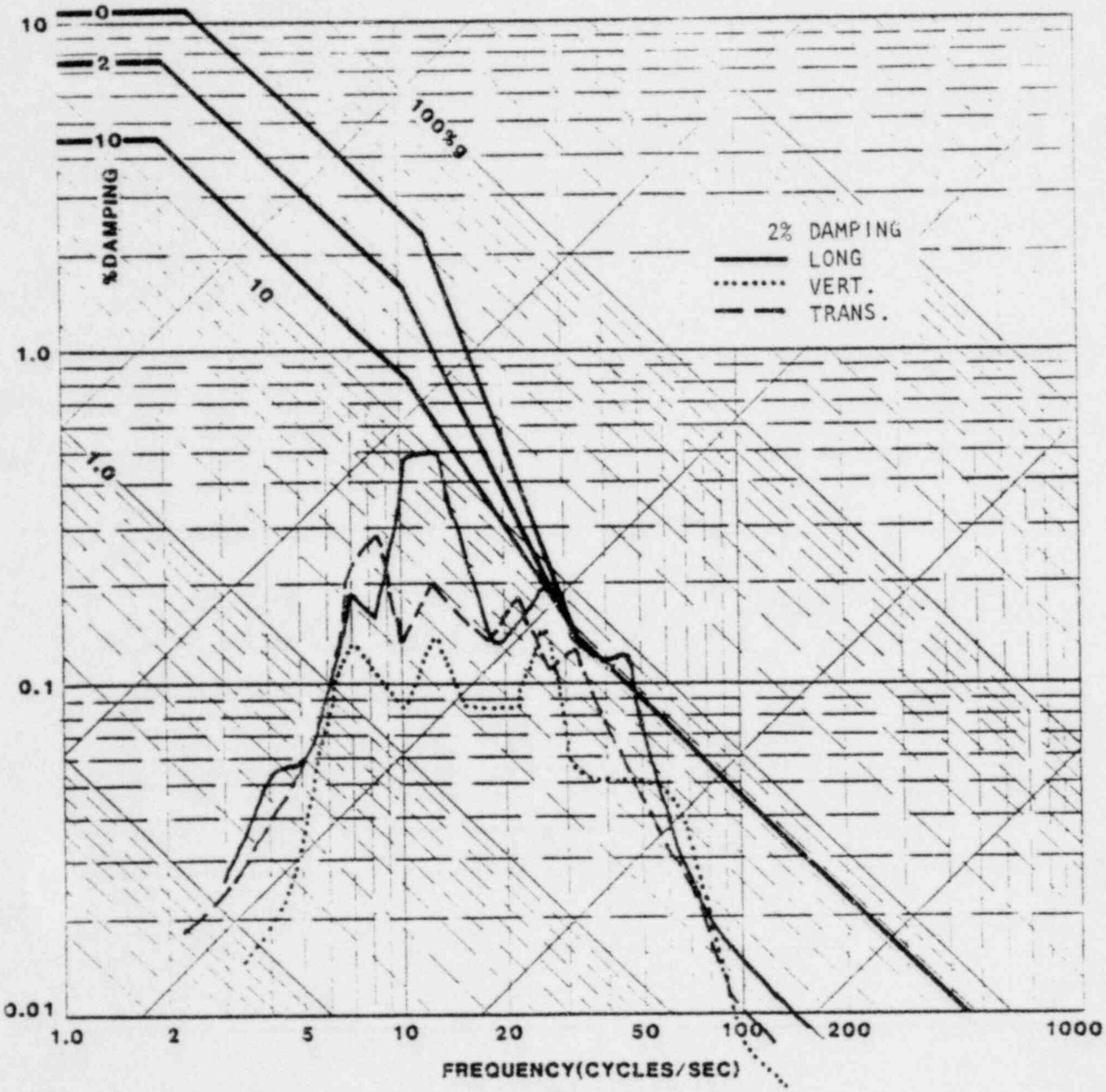
RECORDING DISTANCE 2820 FEET

MAXIMUM CHARGE/DELAY 410 LBS.

COMPONENT OF MOTION TRANSVERSE

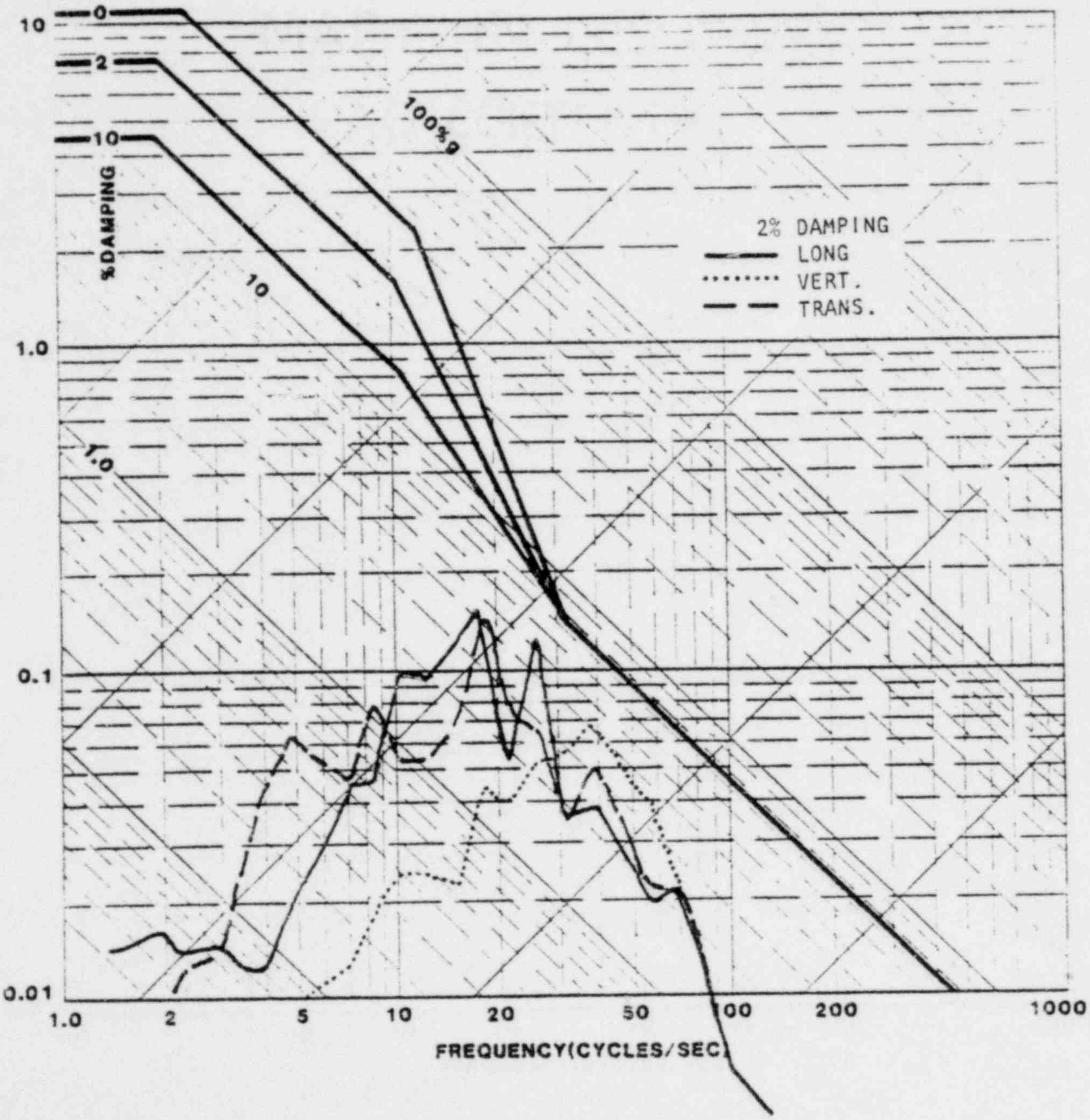
MEASURED PEAK VELOCITY .03 IN/SEC

FIGURE 4f



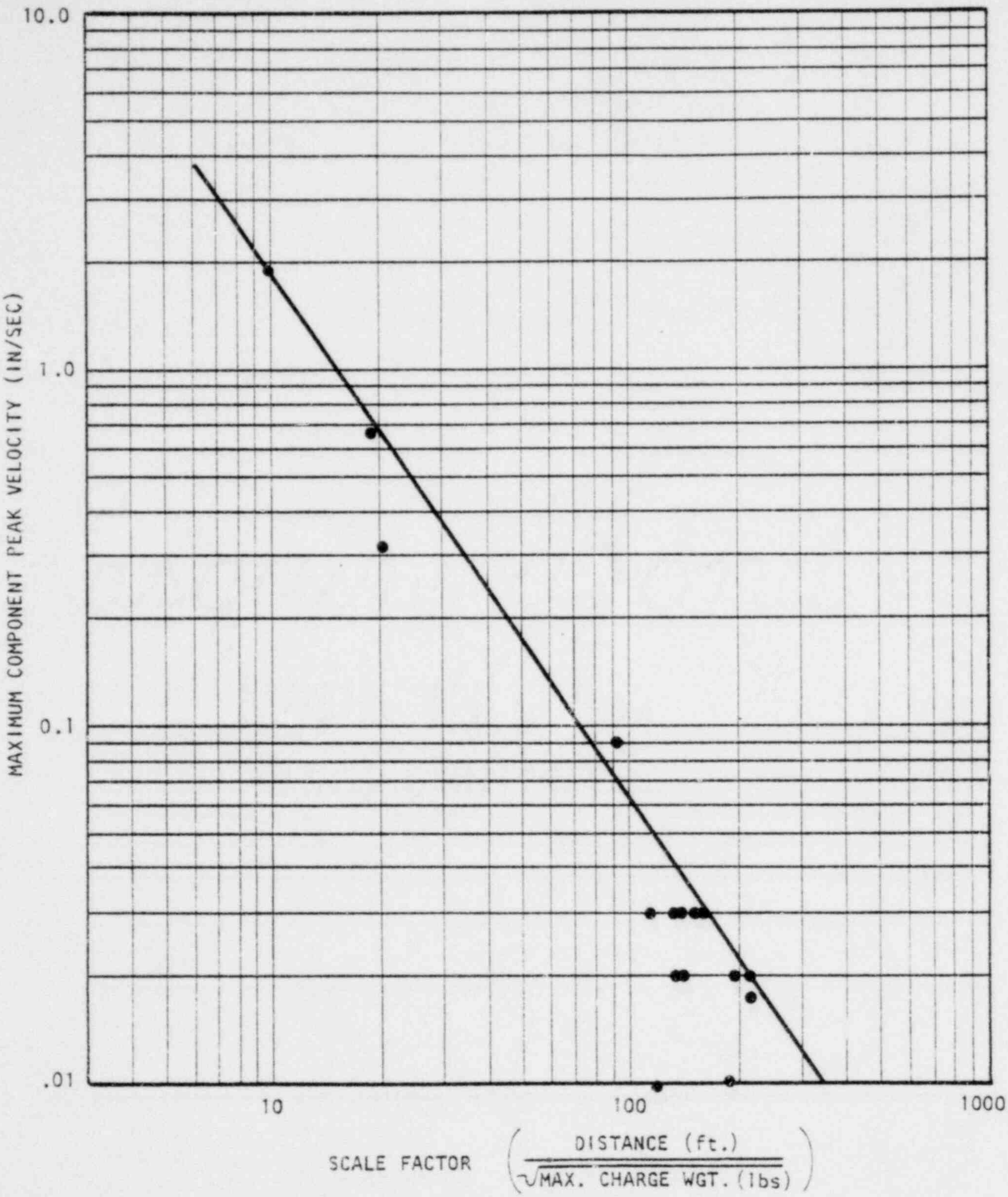
OBE DESIGN SPECTRA AND 2% SPECTRA OF BLAST OF 2/4/80 (410LBS) RECORDED AT ELECTRIC SUBSTATION AT A DISTANCE OF 1850 FT.

FIGURE 5a



OBE DESIGN SPECTRA AND 2% SPECTRA OF BLAST OF 2/4/80 (410 LBS., RECORDED AT 2820 FEET) SCALED TO 3300 FT.
(MINIMUM DISTANCE OF QUARRY FACE TO REACTOR BUILDING)

FIGURE 5b



SITE SPECIFIC ATTENUATION OF PEAK COMPONENT PARTICLE VELOCITY FROM QUARRY BLASTING NEAR LIMERICK STATION

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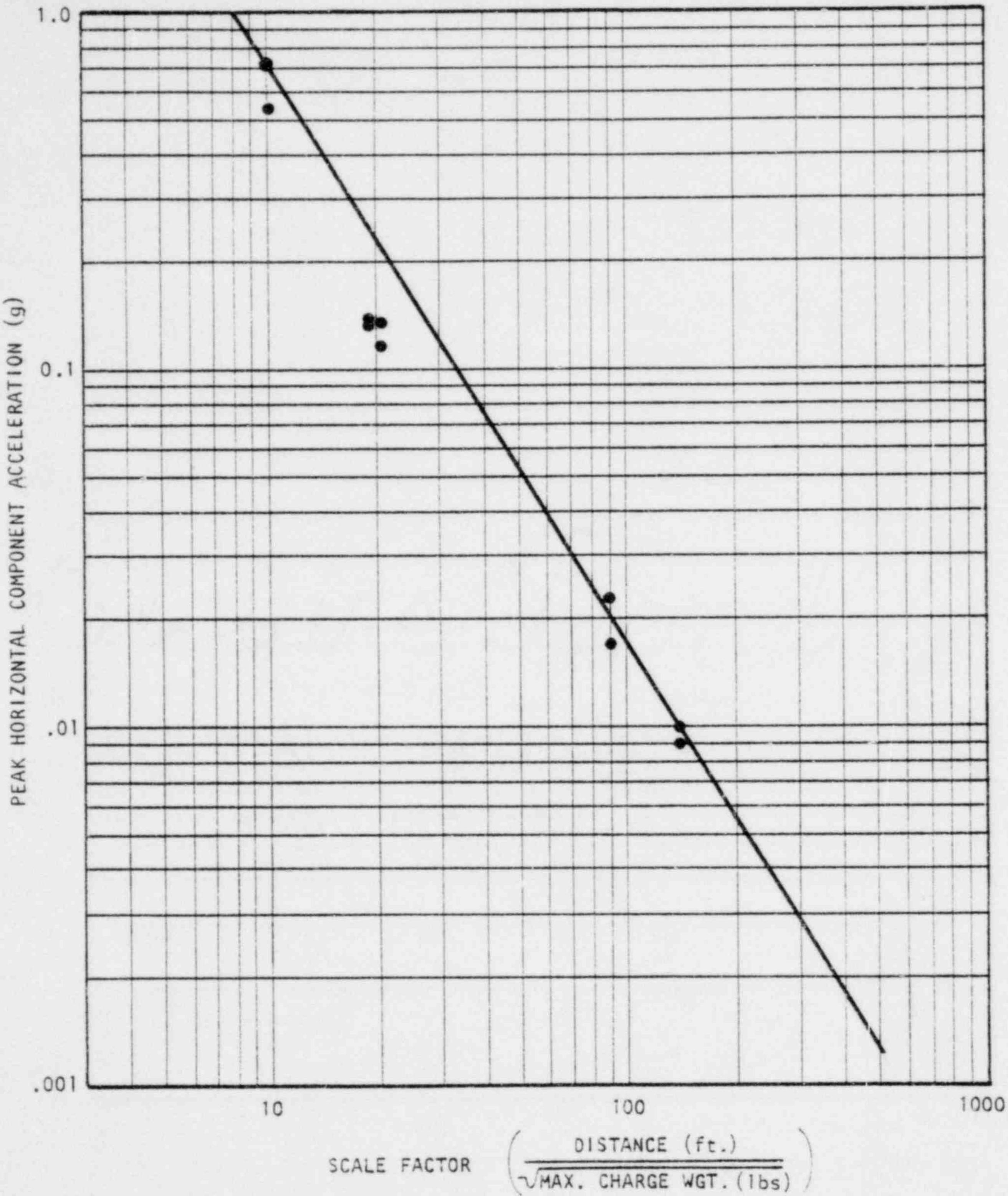
FIGURE 6



SITE SPECIFIC ATTENUATION OF PEAK HORIZONTAL ACCELERATIONS FROM QUARRY BLASTING NEAR LIMERICK STATION

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FIGURE 7