SPECTRAL ANALYSIS OF PERRY NUCLEAR POWER PLANT VELOCITY-TIME HISTORIES RESULTING FROM OHIO EARTHQUAKE

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February 25, 1986

Several time history signals from two separate locations of the Perry NPP were recently obtained by LLNL from Kinemetrics. These signals are response motion data recorded at the Perry Plant due to the January 31, 1986, Ohio earthquake. The two locations are denoted as Station-1 (located on the foundation mat) and Station-2 (located on the containment vessel). The data from each station contained acceleration, velocity, and displacement time histories in three orthogonal directions (south, west, and vertical).

These signals were originally presented to the Dynamic Test and Analysis Group as data files on the Livermore Main Frame Computer System. They were subsequently downloaded to floppy disks and processed on an IBM-PC to obtain various frequency domain information.

The purpose of our study was to obtain as much information as possible from these signals concerning the way in which the energy was distributed in the frequency domain. Since kinetic energy is directly proportional to velocity squared, it seemed most appropriated to work with the velocity time history signals. Furthermore, we worked with the data files that were previously corrected by Kinemetrics. It was specifically requested by the NRC that we provide them with Power Spectral Density (PSD) functions which are defined as the Fourier transform of the autocorrelation function [1]. Furthermore, it can be shown that this is also equal to the modulus squared of the Fourier transform of the velocity time history signal [2].

For each of the six velocity signals (Stations 1 and 2 in the south, west, and vertical direction) we obtained the Fourier transform of the signal (on the IBM PC) and then formed the modulus squared to obtain the desired PSD functions. These PSD functions describe the way the energy of the signal is distributed in the frequency domain. The units of the PSDs are (velocity/frequency) squared, where the velocity is specified in cm/sec and the frequency is given in Hz. Once the PSDs were obtained, they were integrated (Simpson's 1/3 Rule) to obtain a cumulative energy frequency distribution.

For each of the signals processed, we present two figures. The first figure shows the (corrected) time history signal (cm/sec) on the top with the corresponding PSD on the bottom. The second figure again shows the PSD on the top with its integral (cumulative distribution) on the bottom. Note that the cumulative distributions have all been normalized to unity. Thus, it is possible to determine the percent of the total energy contained in any desired frequency band.

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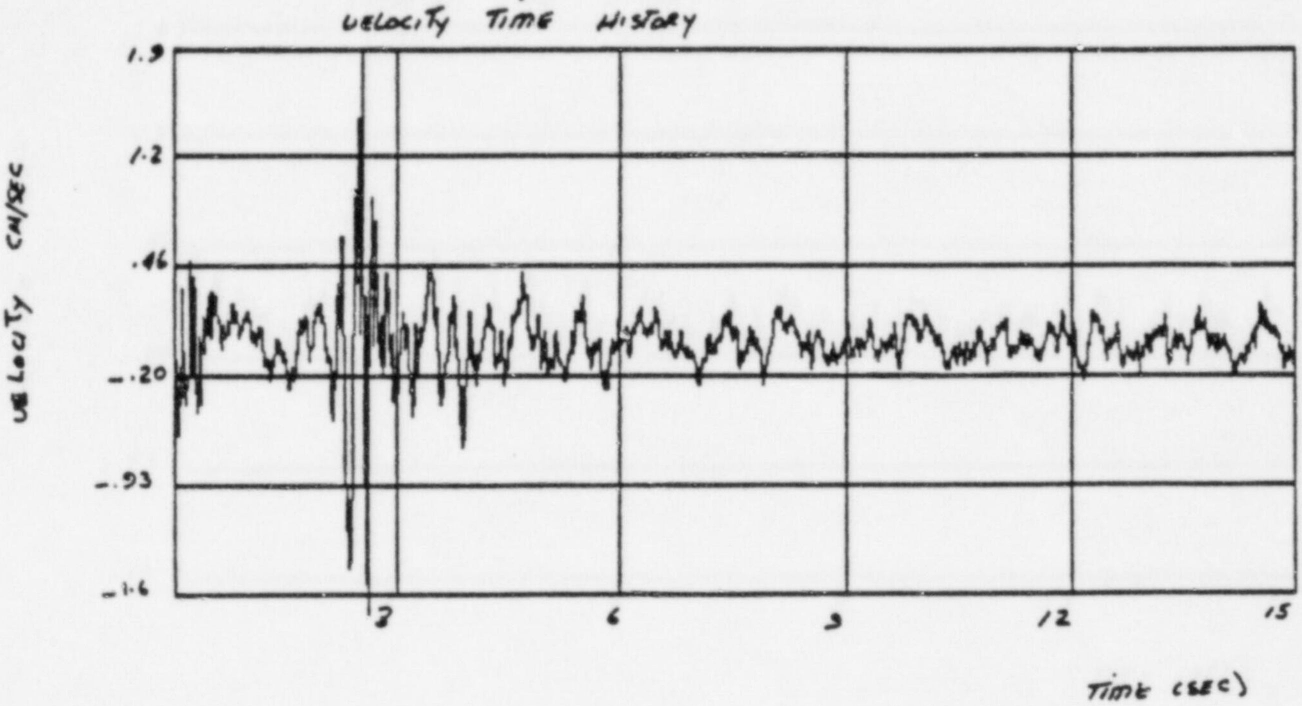
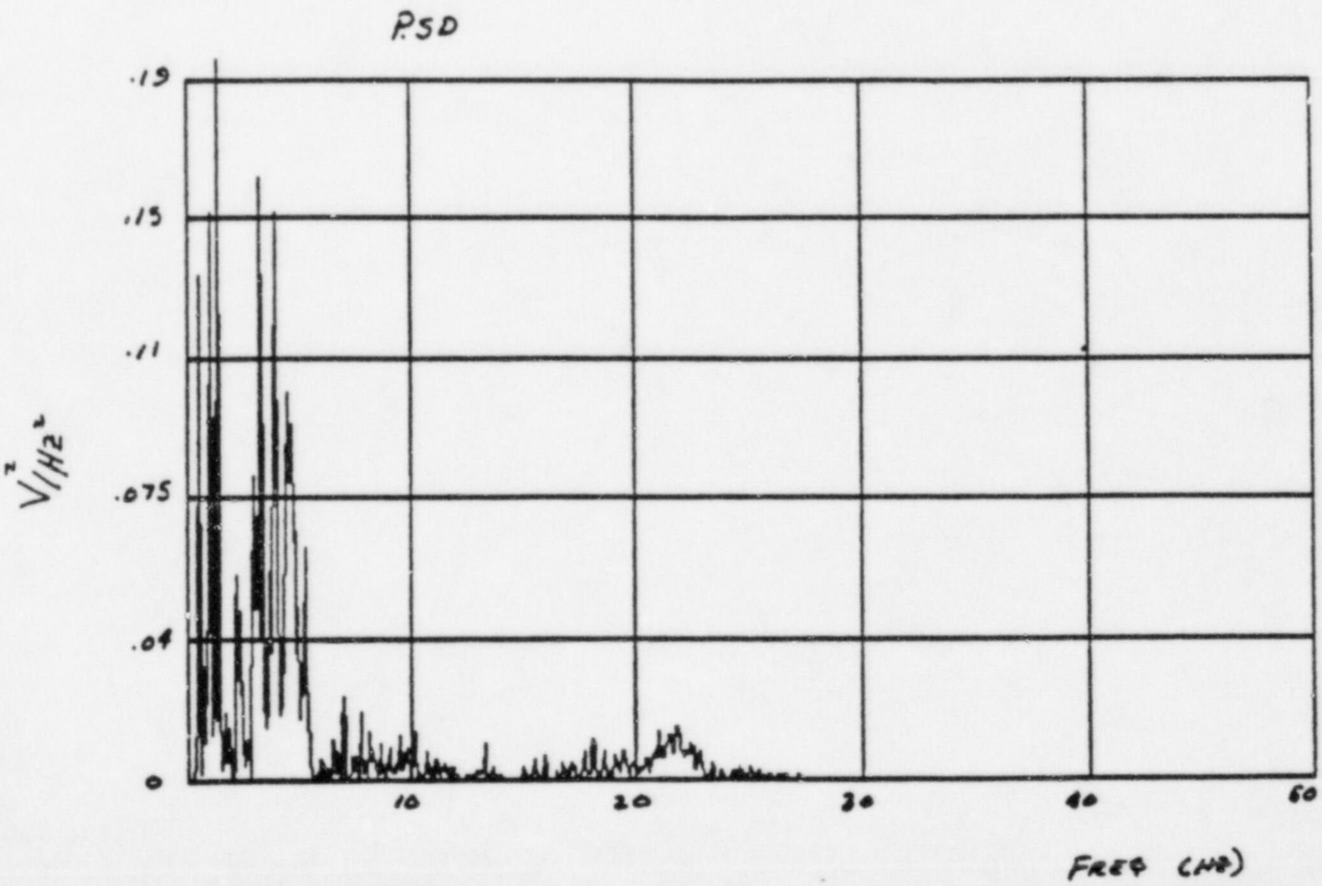
REFERENCES

[1] Bendat, J. S. and Piersol, A. G., "Engineering Applications of Correlation and Spectral Analysis," John Wiley & Sons Publishers, 1980.

[2] Weaver, H. J., "Applications of Discrete and Continuous Fourier Analysis," John Wiley & Sons Publishers, 1983.

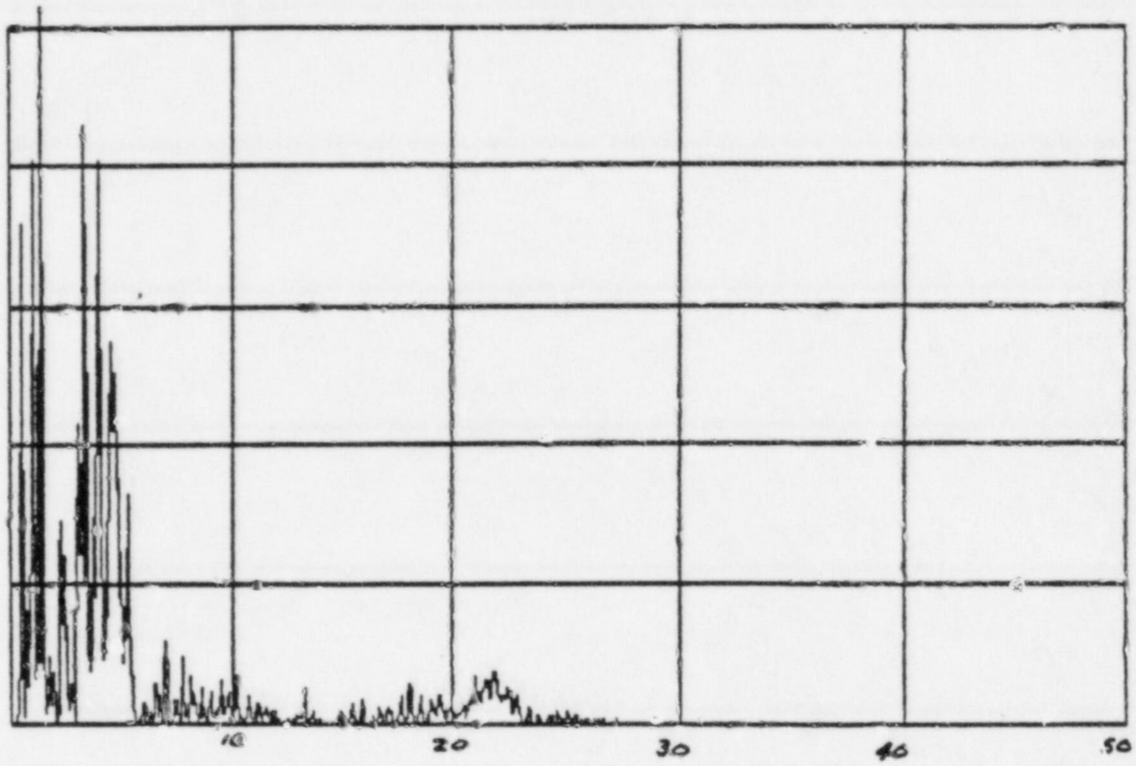
STATION 1 South



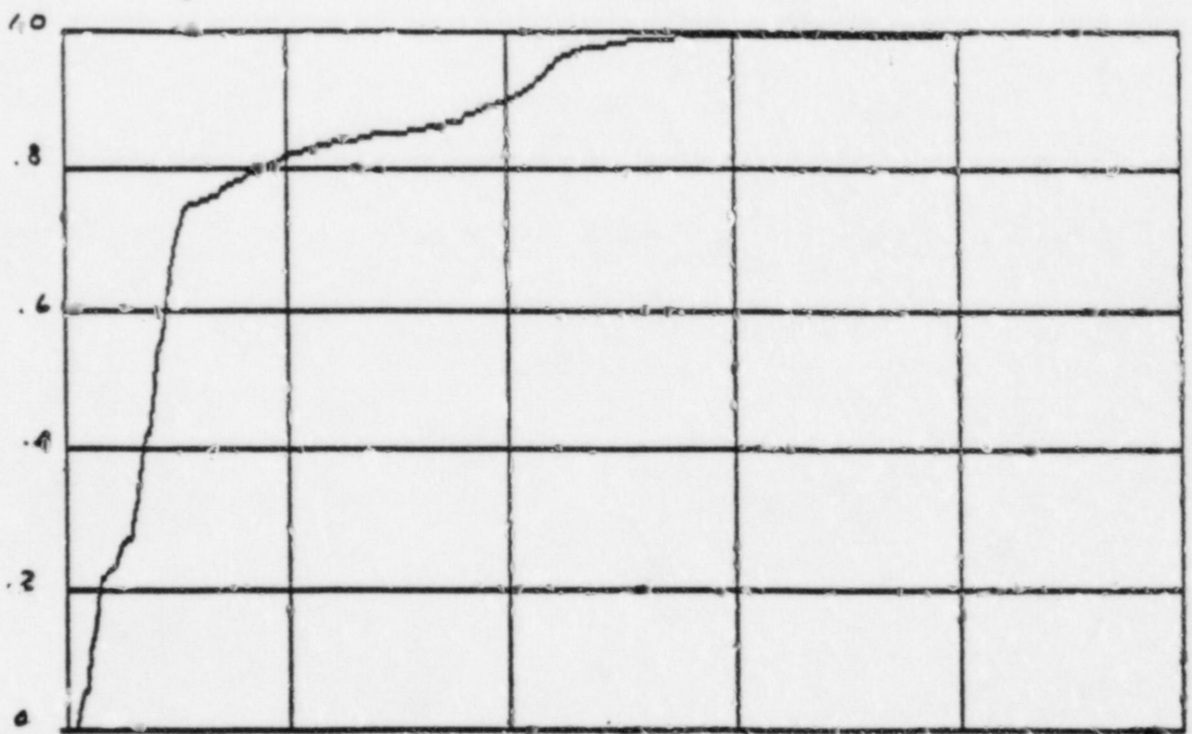


STation 1 South

VELOCITY PSD

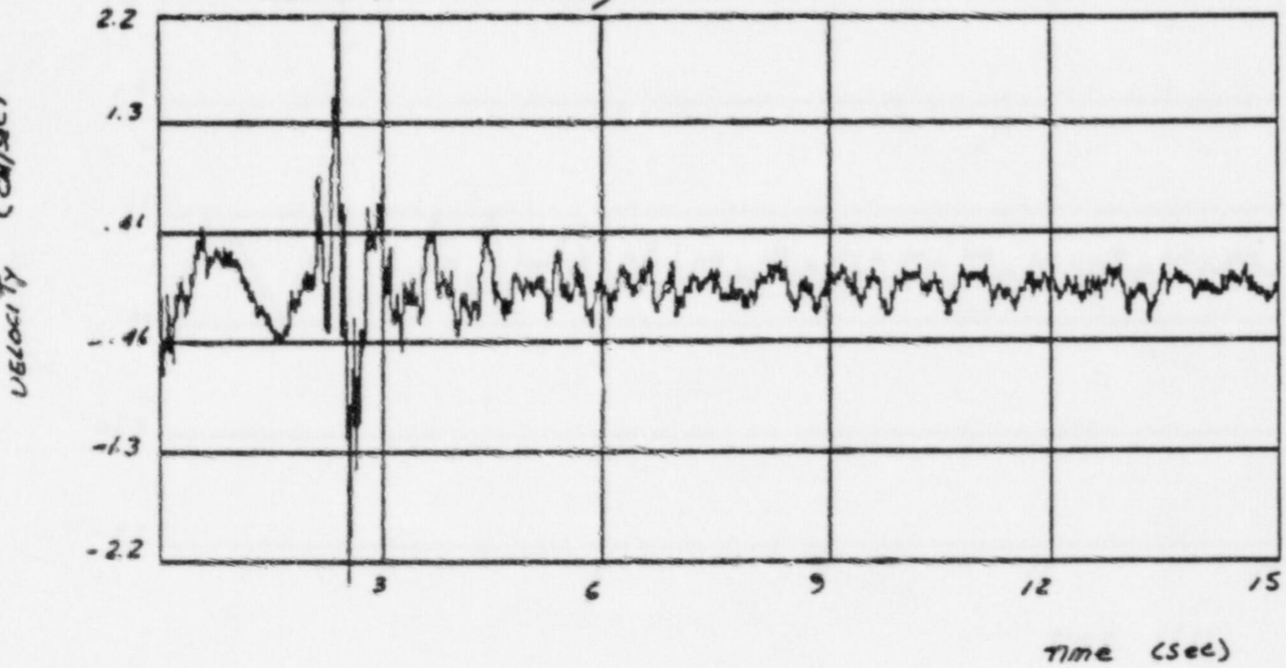


∫PSD

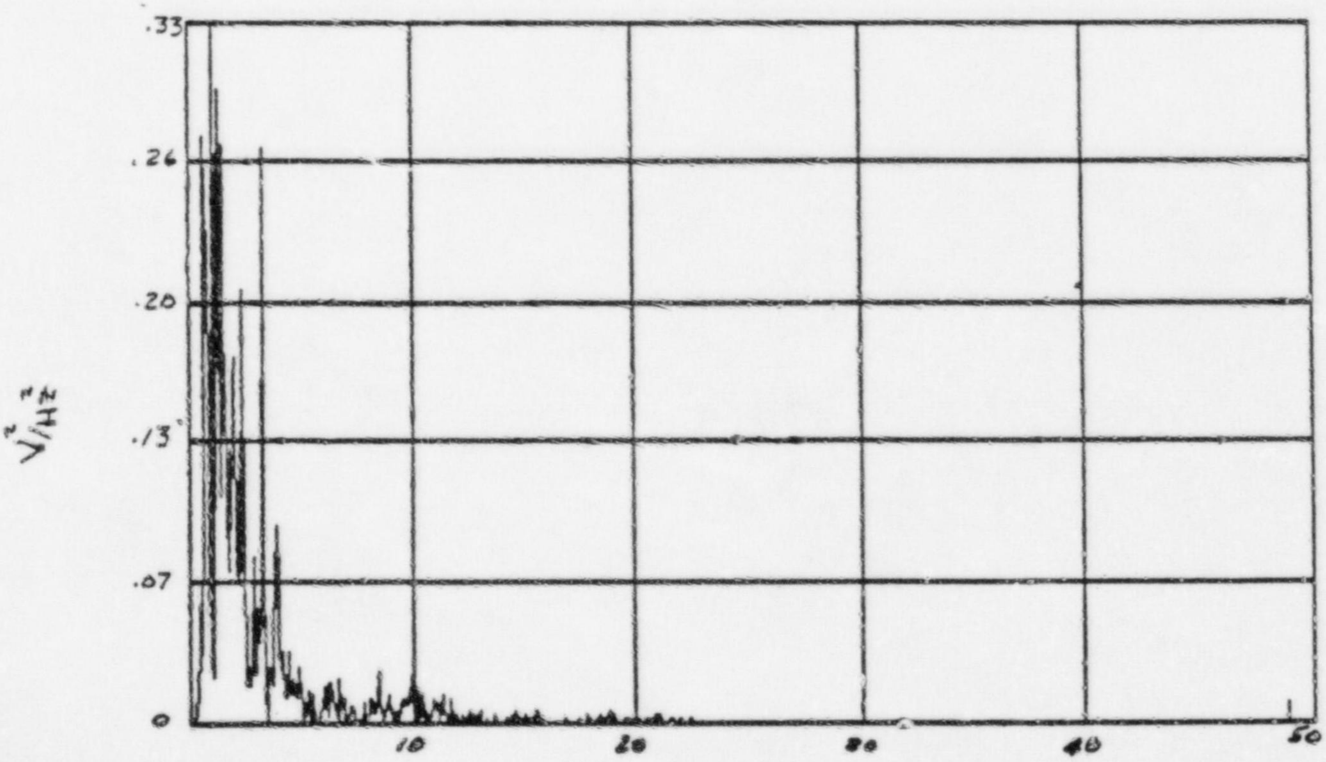


STATION 1 WEST

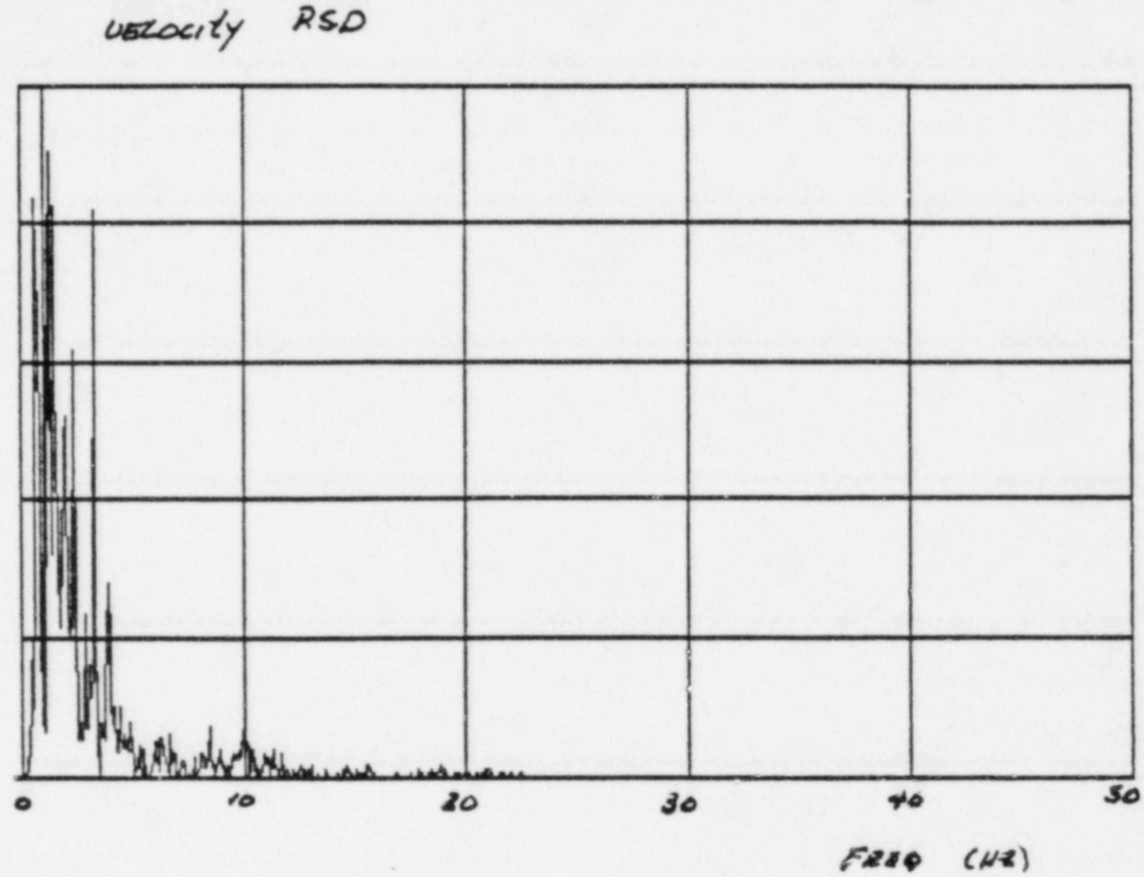
VELOCITY TIME HISTORY

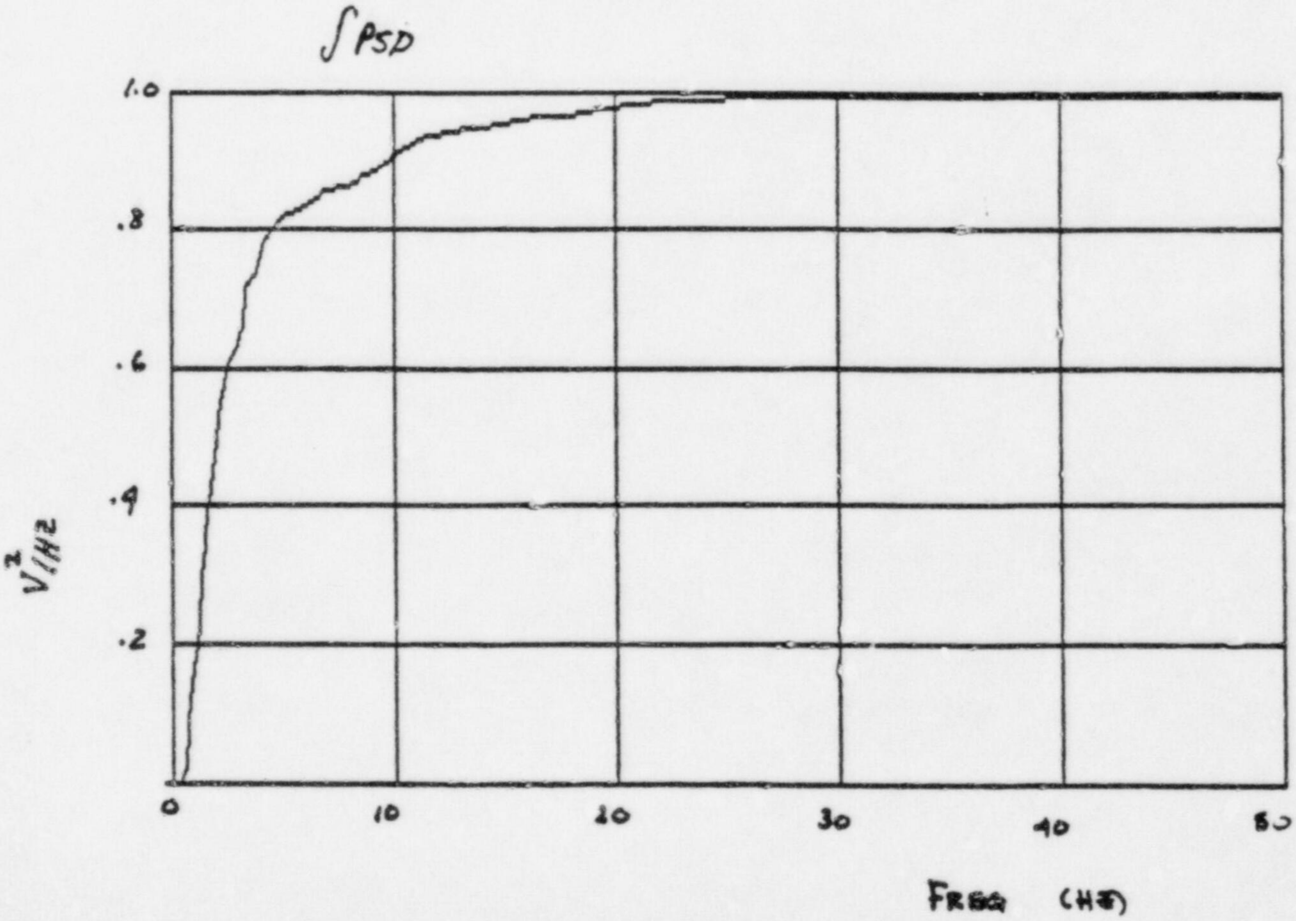


PSD

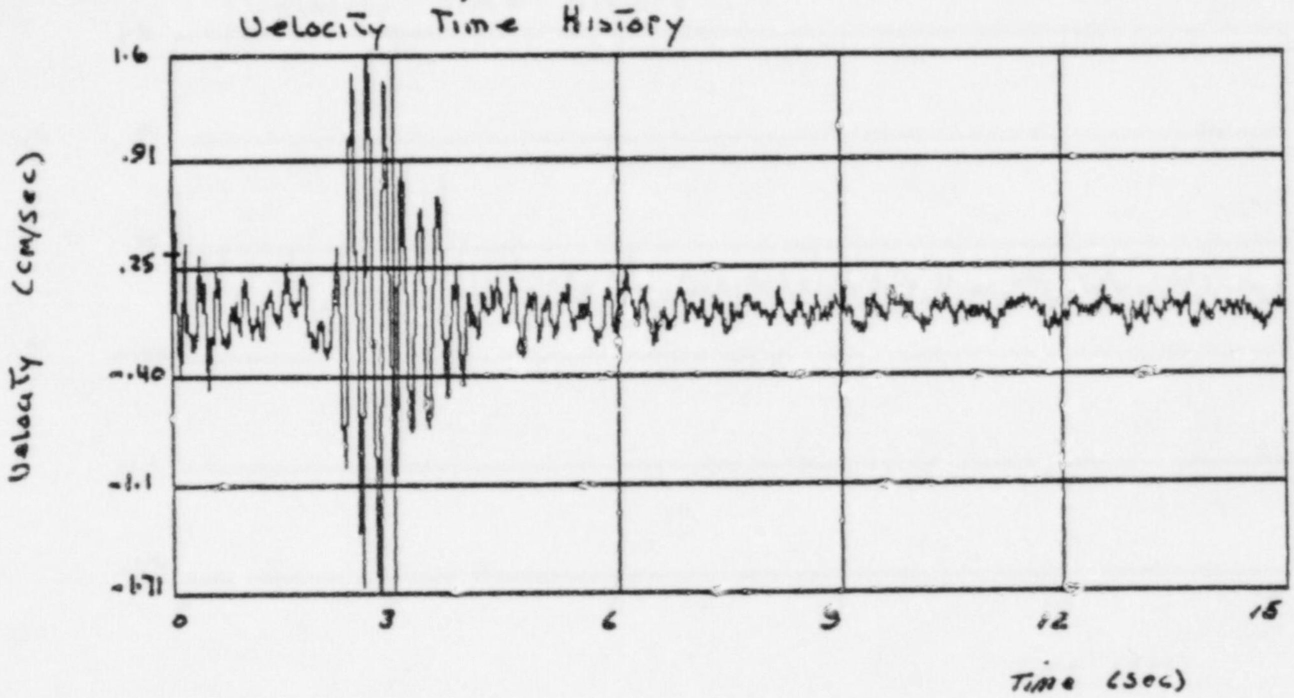


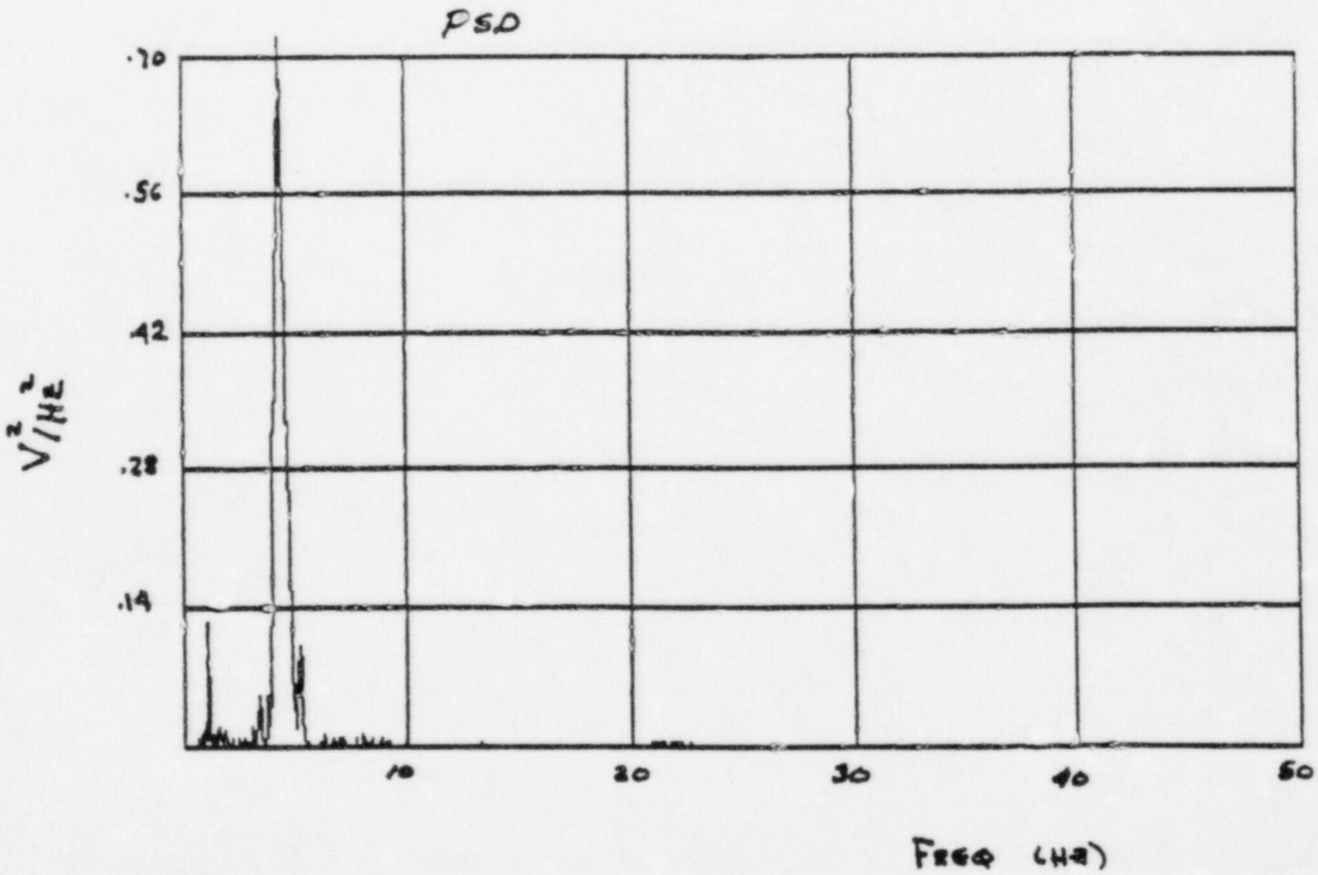
STATION 1 WEST





STATION 1 VERTICAL





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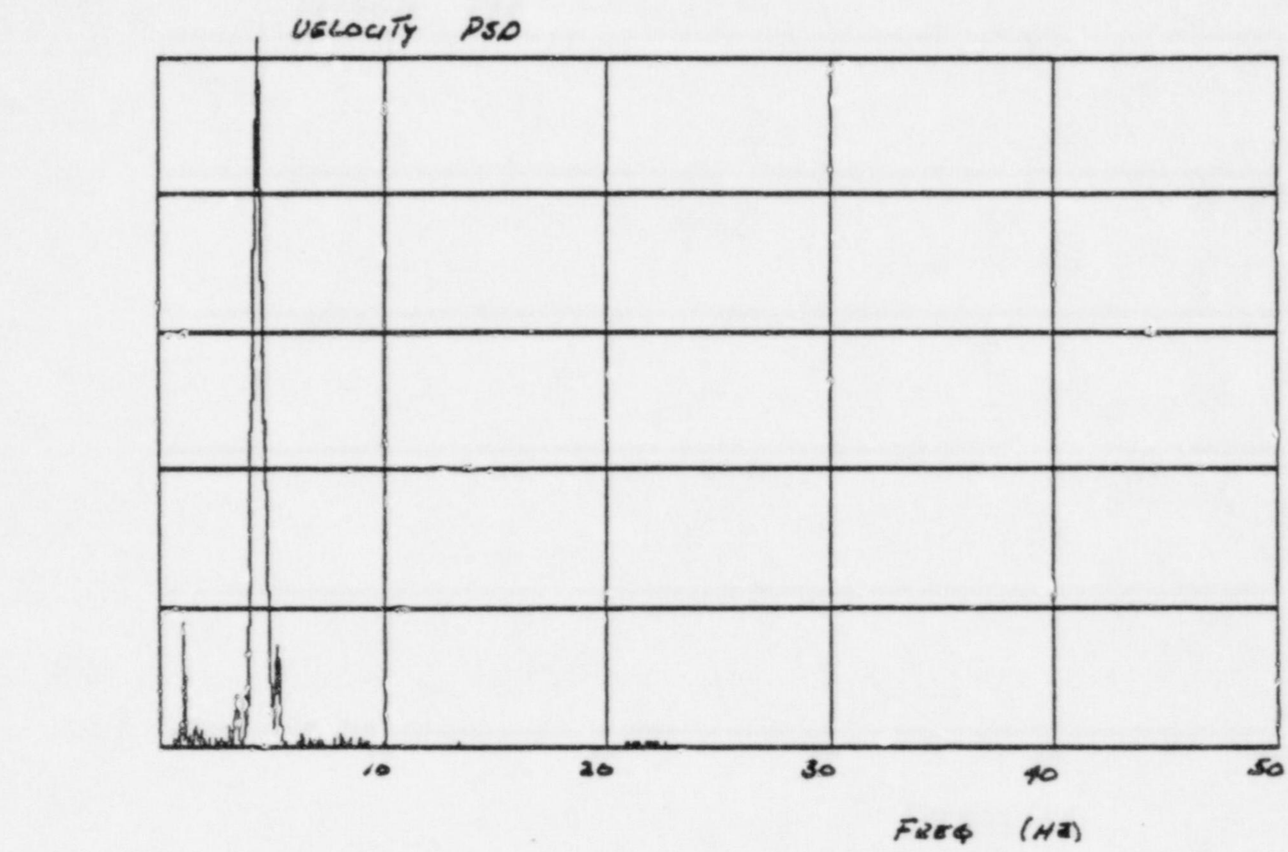
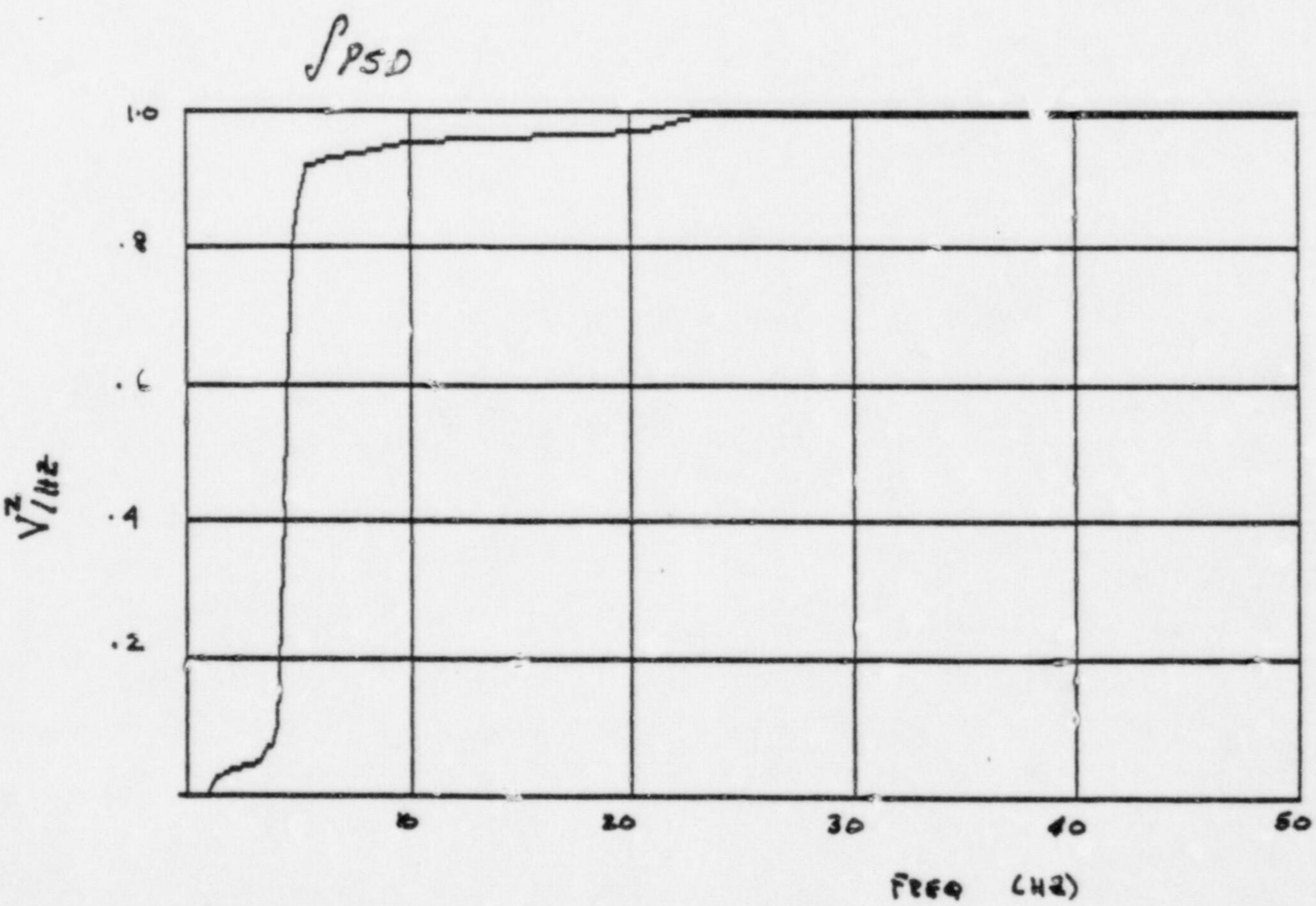
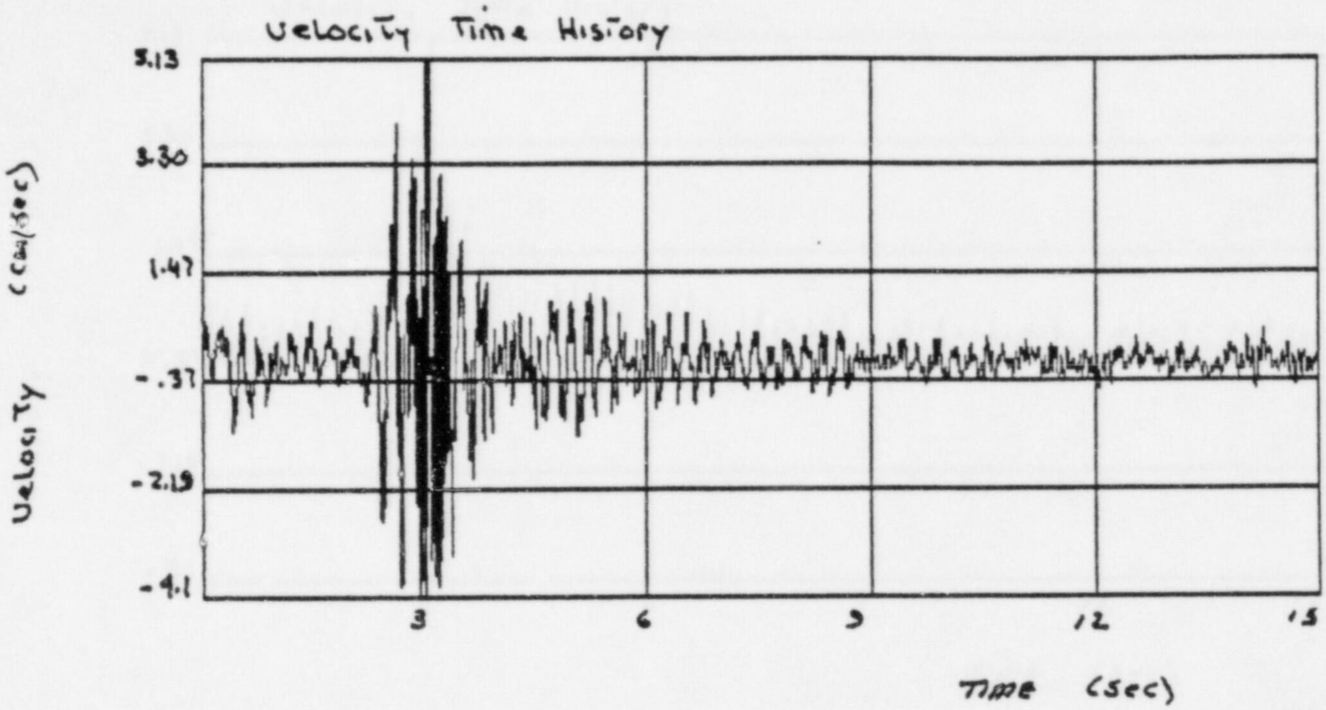
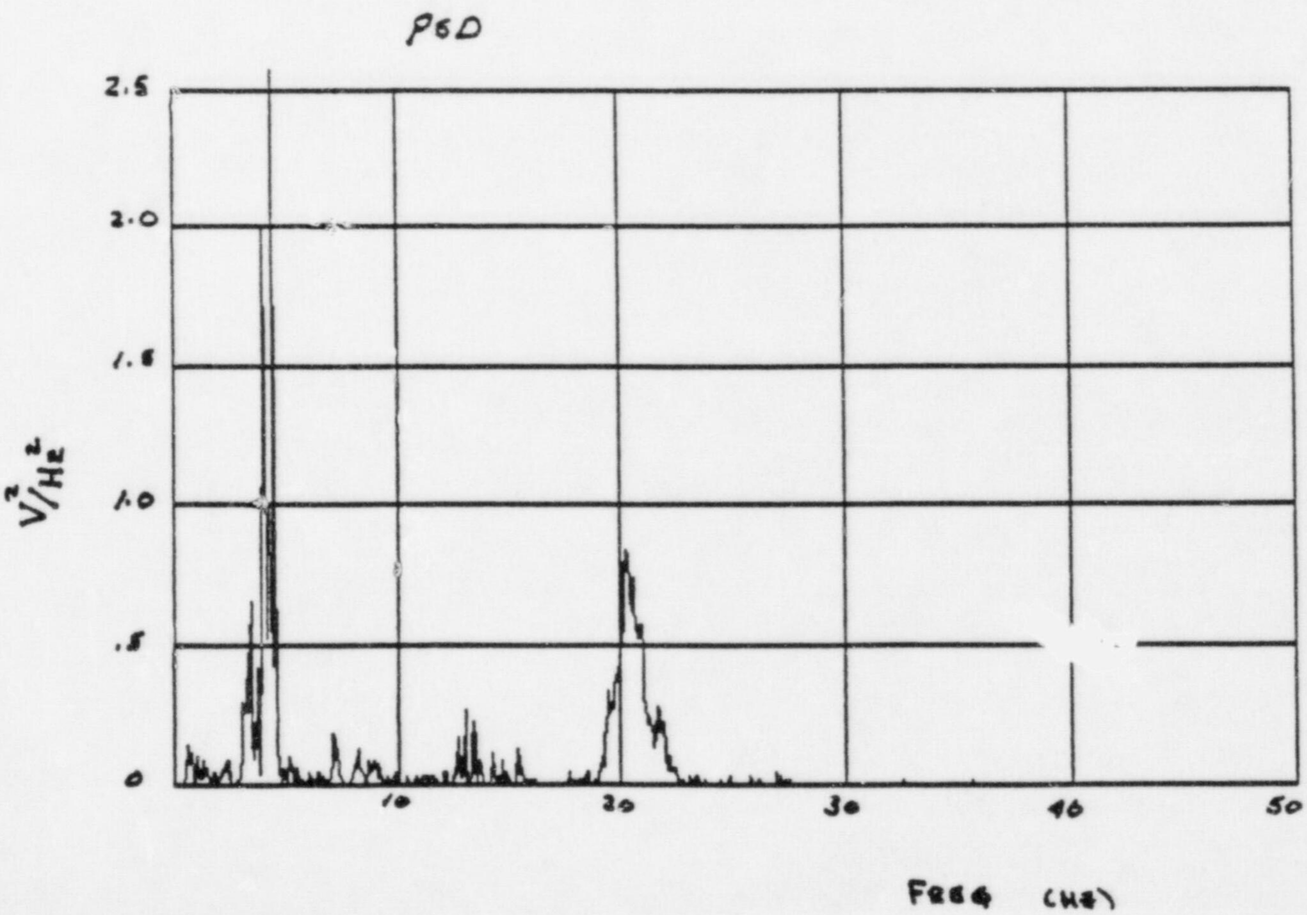


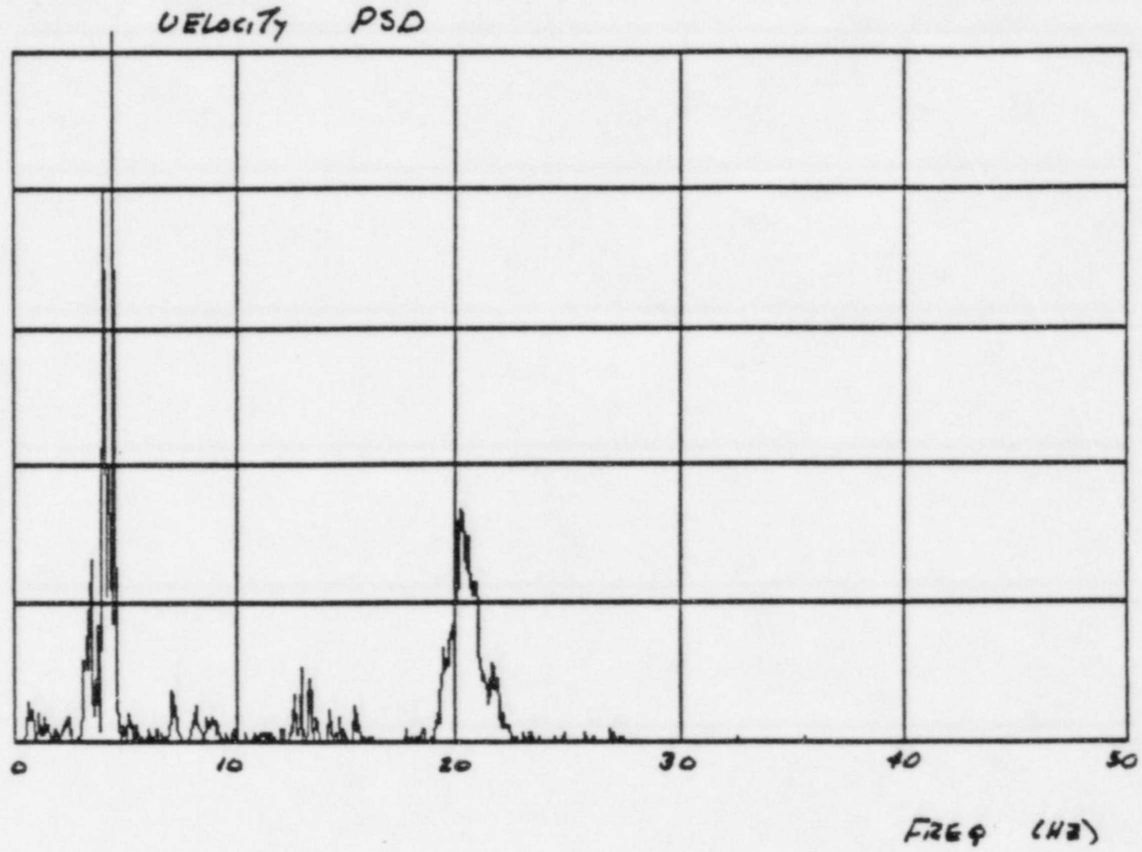


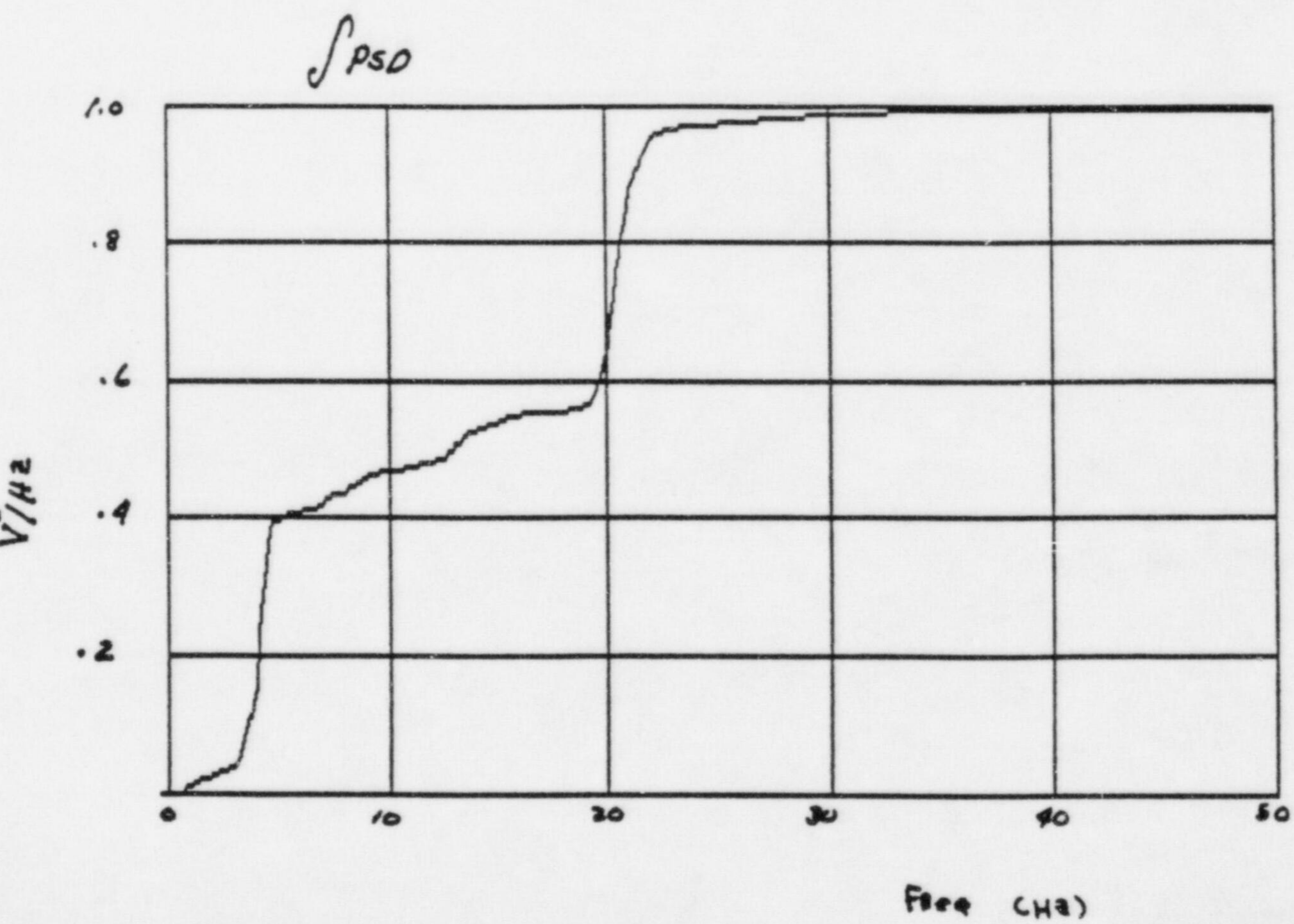
STATION 2 South



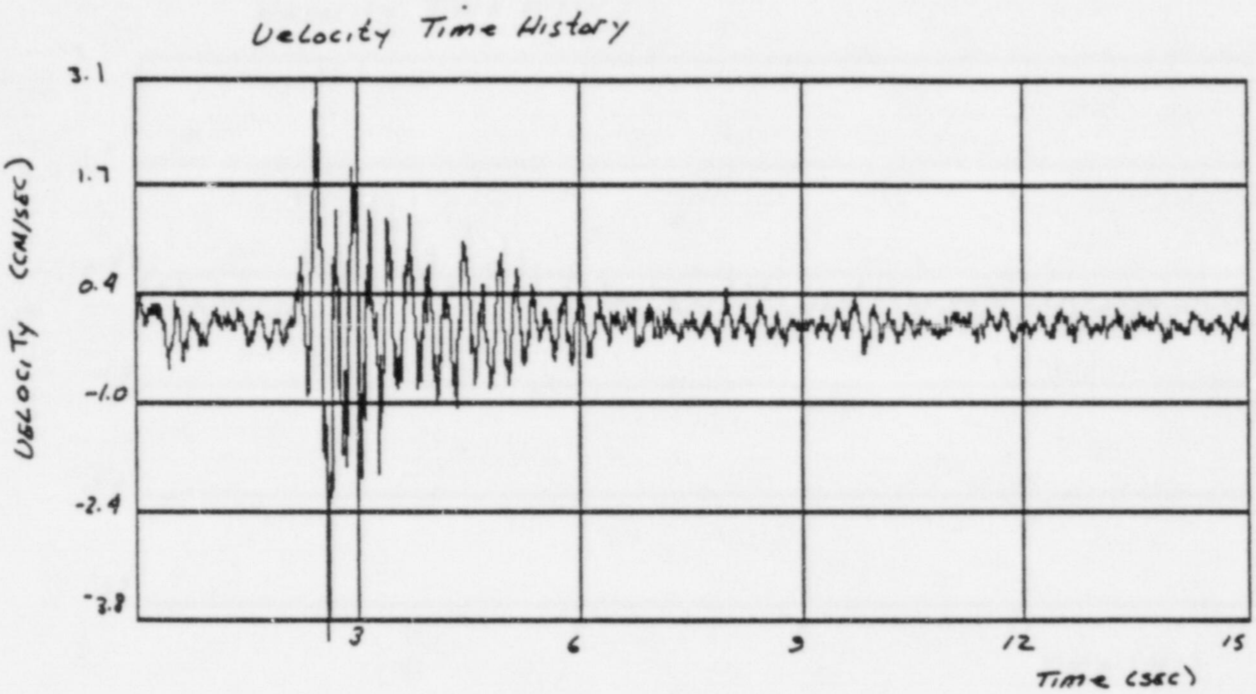


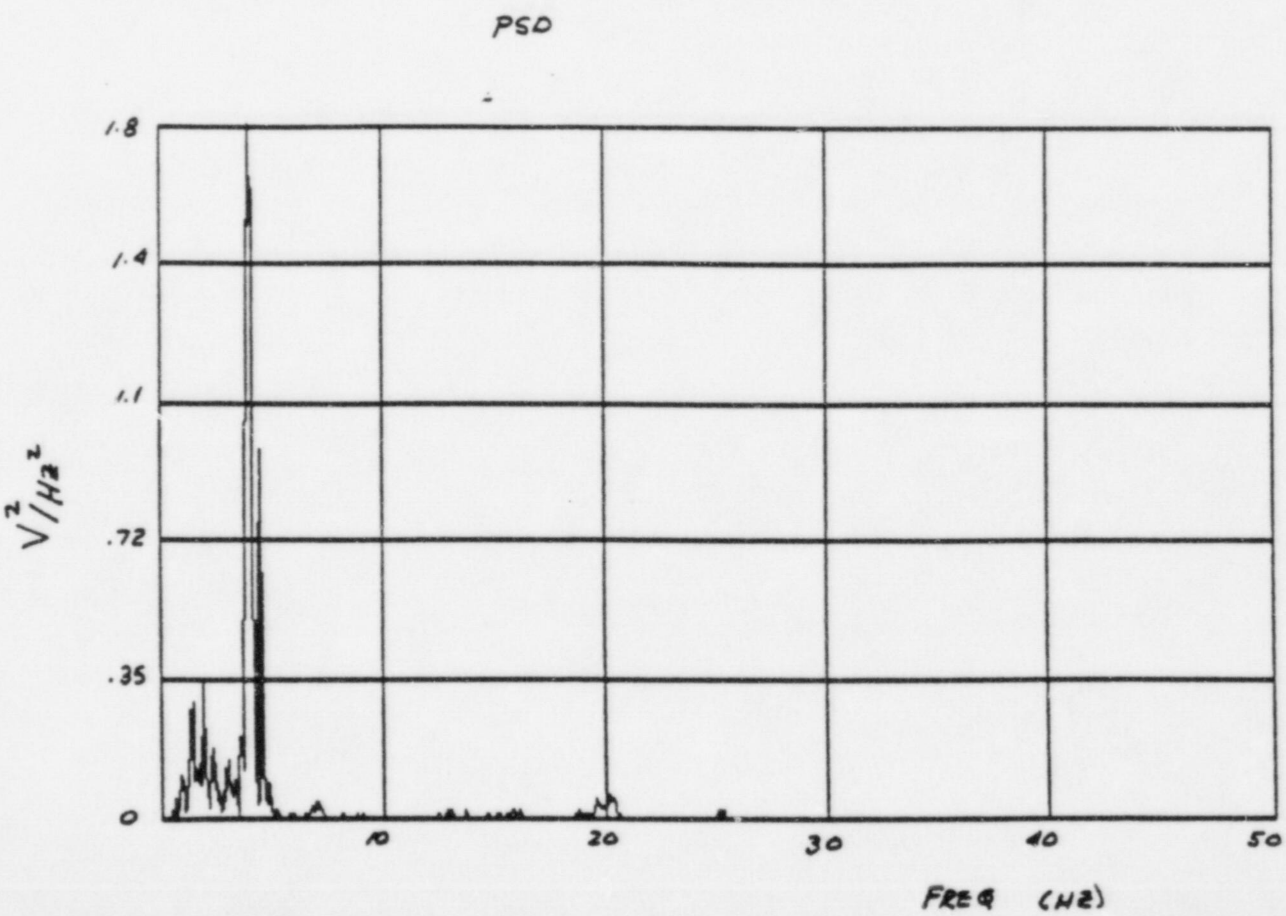
STATION 2 South





STATION 2 WEST





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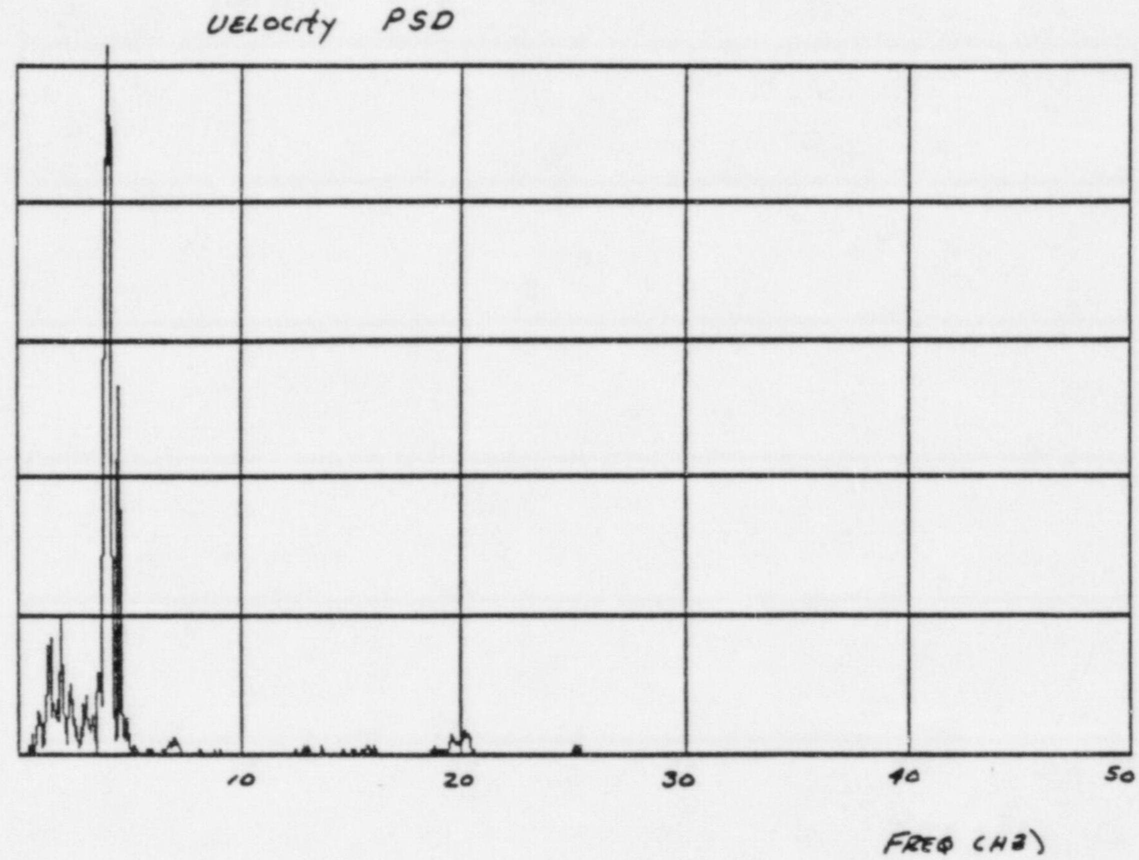
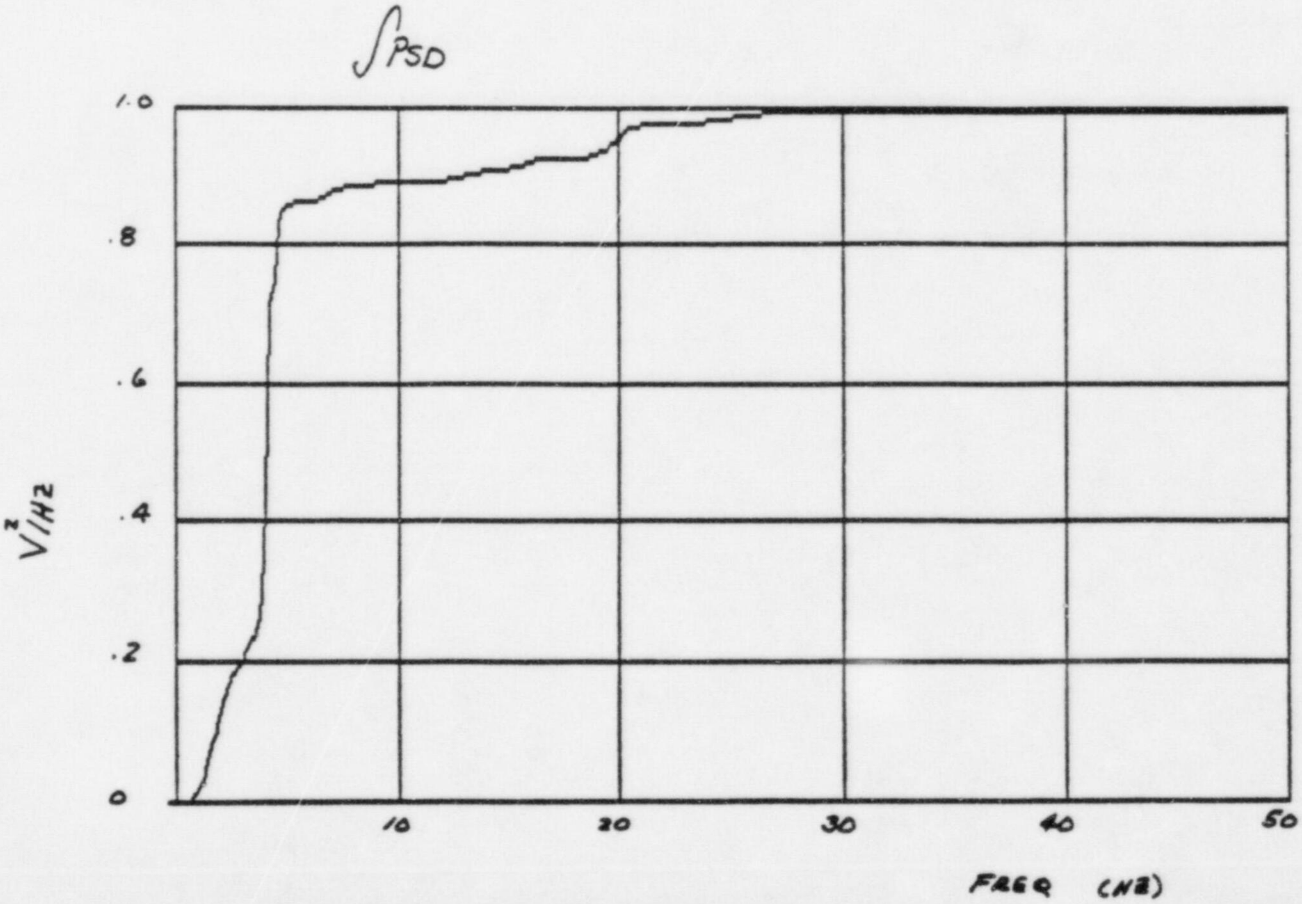
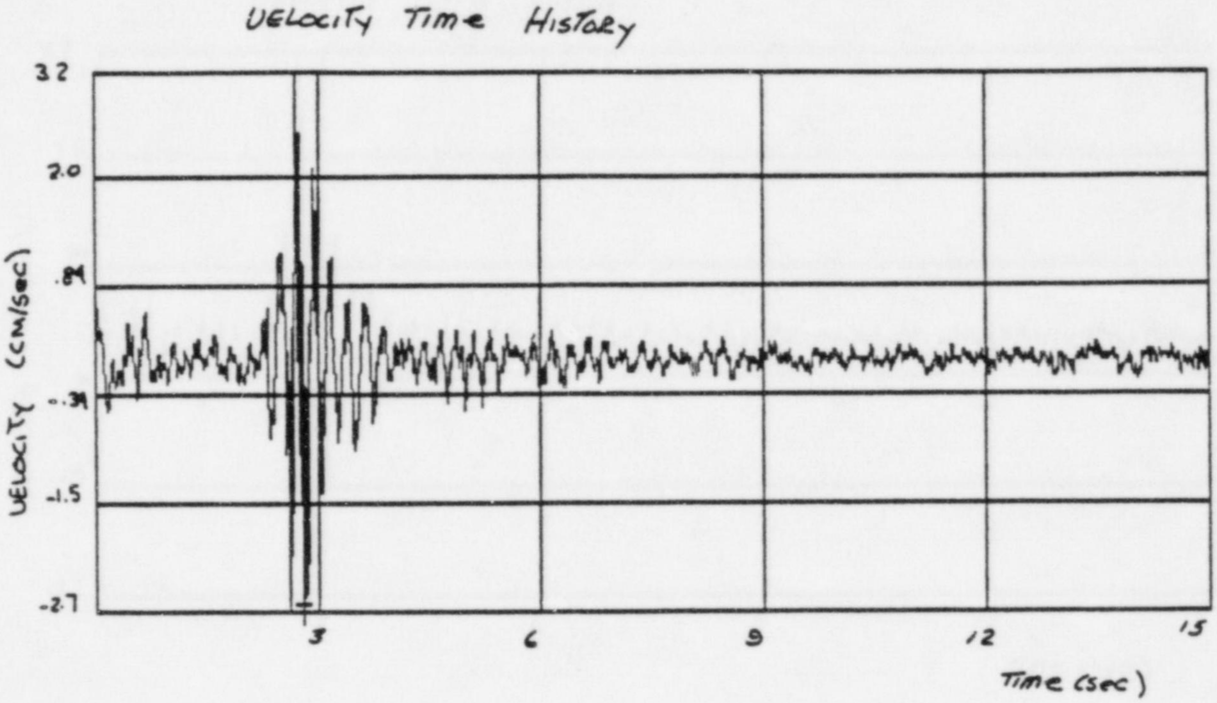
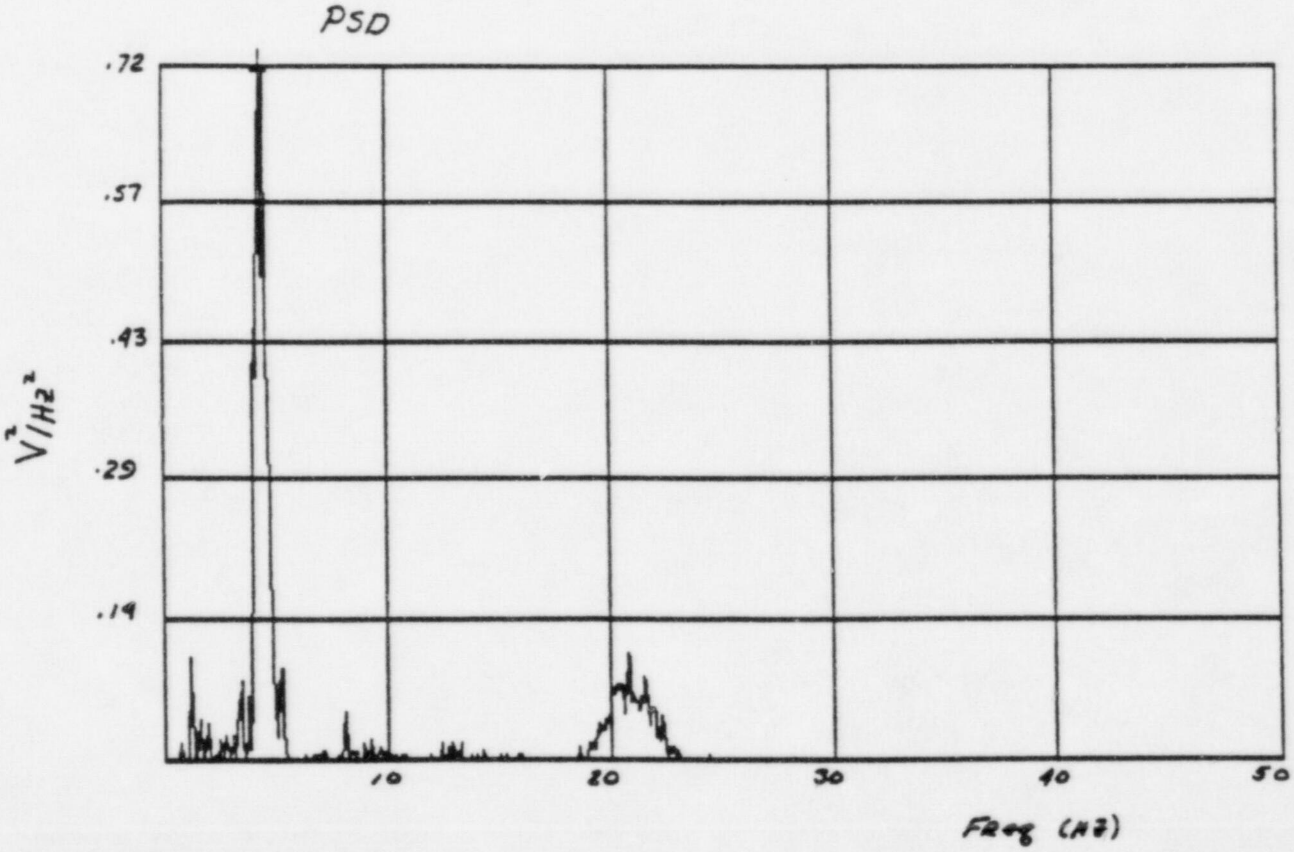


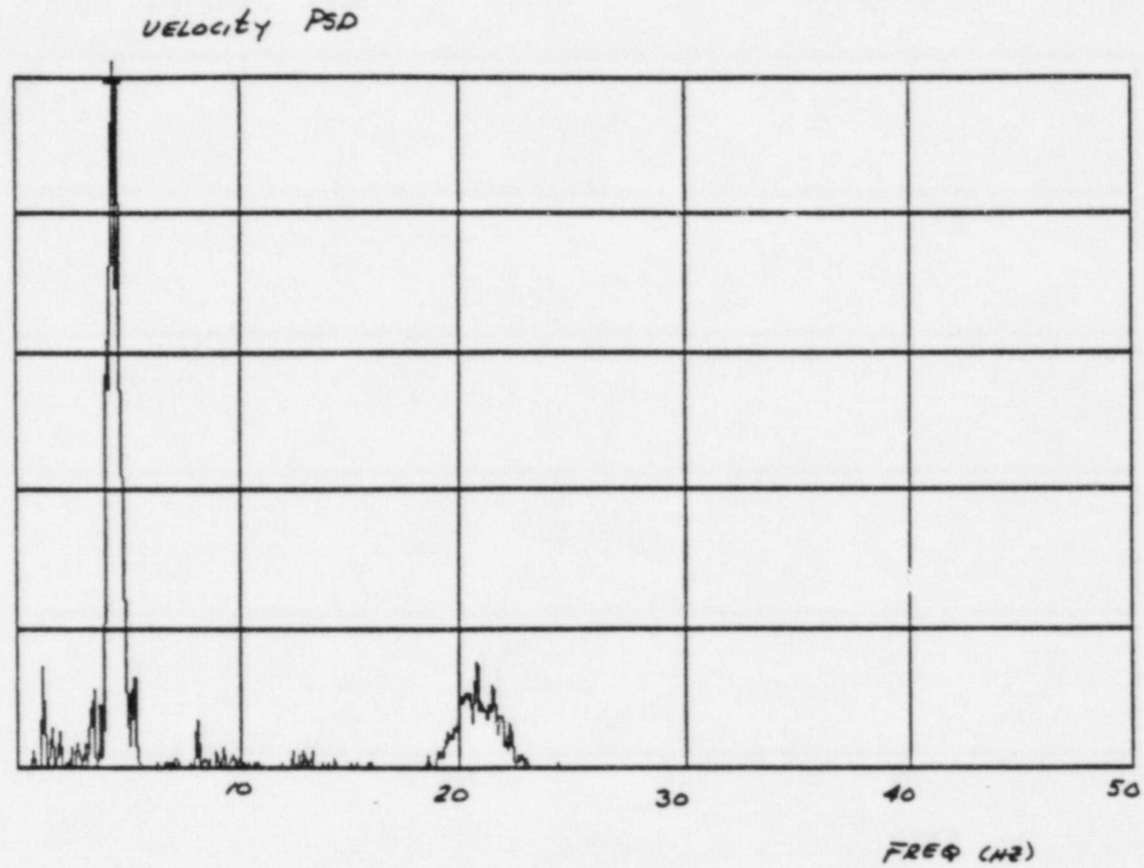


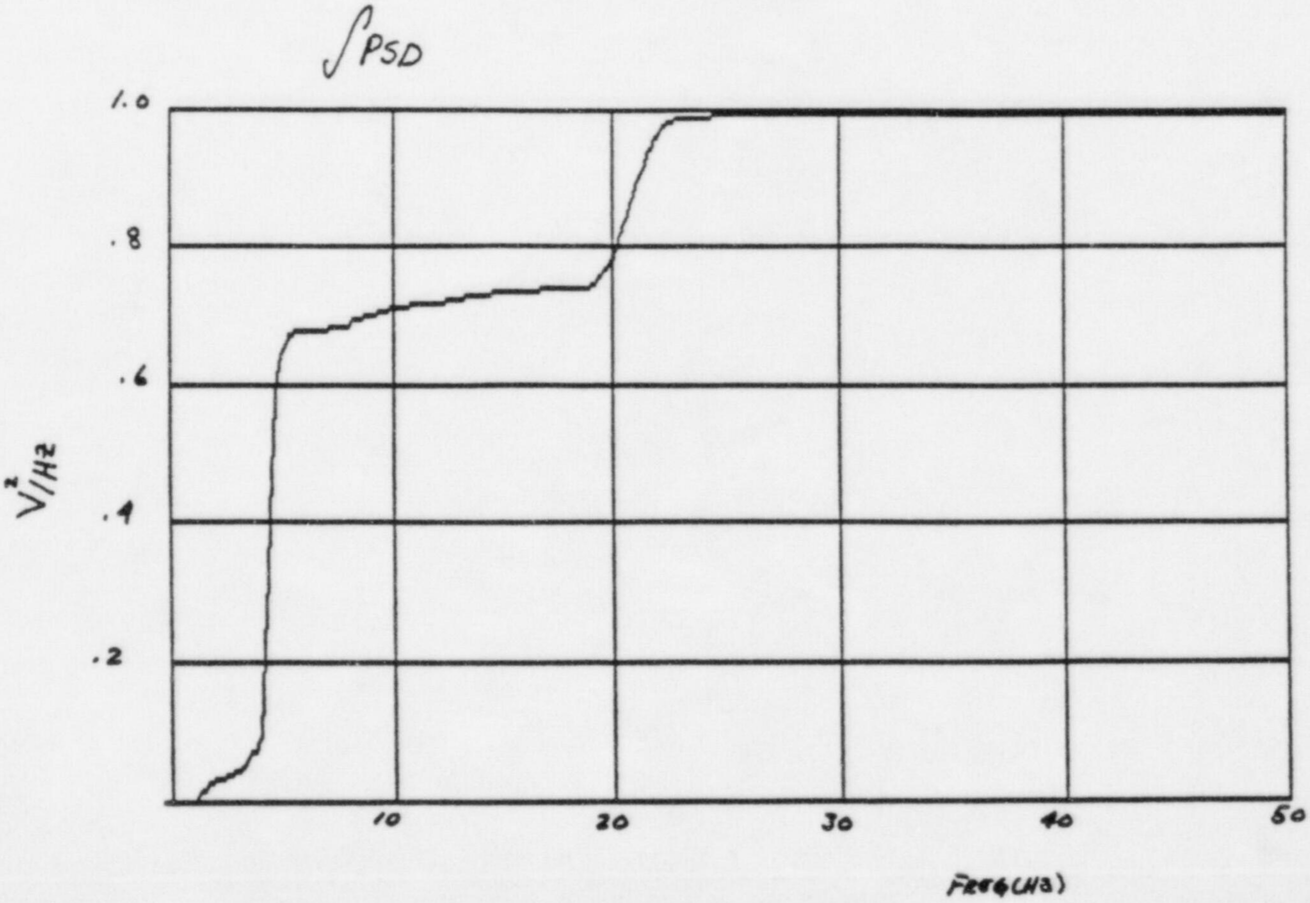
Station 2 VERTICAL





STATION 2 VERTICAL





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February 26, 1986

Mr. Robert Hermann
Division of Boiling Water Reactor Licensing
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US Nuclear Regulatory Commission
Phillips Building
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Bethesda, Maryland 20014

Subject: Contributions to the Revised Perry SER due to the January 31, 1986 Earthquake

Dear Bob:

Please find enclosed my contribution to the revised Perry SER subsequent to the January 31, 1986 earthquake. I am currently completing documentation of the effort I expended on Perry in a Technical Evaluation Report -- however, it could not be completed within this deadline. I hope this information is helpful. Please give me a call to discuss it further.

Sincerely,

James Johnson

James J. Johnson

JJJ/jm
Encls.

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Contribution to the Revised Perry SER

Five topics were identified to be discussed relative to the effect of the January 31, 1986 earthquake on the Perry Nuclear Power Plant.

1. Overview of previous SER
2. Changes since the last SER
3. Impact on applicable plant systems of the January 31, 1986 earthquake.
4. Findings and determinations.
5. Conclusions

Contributions to topics 3,4, and 5 for the Perry structures (including soil-structure interaction and structure response) are contained here.

Background

At approximately 11:47 a.m. EST on January 31, 1986, an earthquake occurred of magnitude 4.9 M_b. Its epicenter was 11 miles south of the Perry Nuclear Power Plant. The earthquake was felt at Perry and motions were recorded at several locations in the Perry structures.

Three different types of instruments recorded the event at Perry. One type of instrument is the Kinemetrics Model SMA-3 strong motion time history recording accelerograph. This instrument records the three orthogonal components of acceleration over the duration of the earthquake. Two of these instruments were installed at Perry -- one on the reactor building foundation mat at approximately elevation 575' and the other is mounted on the containment shell at approximately elevation 686'. Plots of the recorded acceleration time histories and calculated response spectra are contained in Ref. 1. These records best describe the characteristics of the earthquake ground motion, i.e. short strong motion duration (less than 1 sec.) and high frequency motion.

The second type of instrument is the Engdahl PSR 1200-H/V response spectrum recorder. This instrument records the response of a series of single degree-of-freedom oscillators to the motion. It generates response spectral ordinates at discrete frequencies, in this case, twelve discrete frequencies ranging from 2 Hz. to 25.4 Hz., for a fixed damping value of 2% of critical. This instrument measures response spectra in three orthogonal directions. Four instruments of this type were used -- two on the auxiliary building foundation mat at an approximate elevation of 568', one on the reactor building foundation mat at an approximate elevation of 575', and one in the reactor building on the drywell platform at an approximate elevation of 630'.

The third type of instrument is the Engdahl Par 400 peak accelerograph. It records three orthogonal components of peak local acceleration. Two instruments of this type were used and were located on the auxiliary building foundation mat at an approximate elevation of 568' and on the reactor recirculation pump at an approximate elevation of 605'. A third instrument was out of service.

3. Impact on applicable plant systems of the January 31, 1986 earthquake.

The scope of the review includes the seismic system and subsystem analysis of the plant including Category I structures and systems. The impact of the January 31, 1986 earthquake on the seismic design of structures and on the seismic analysis methods including soil-structure interaction and structure response is reviewed.

4. Findings and determinations

The bases for this preliminary evaluation are as follows:

(i) Submittals by the utility (Refs. 1, 2, and 3)

(ii) Follow-up and clarifying conversations with the utility and its architect-engineer.

(iii) Recorded acceleration time history records obtained from tape.

(iv) References in the open literature concerning the effects of earthquake characteristics, such as frequency content and duration, on structures.

(v) Independent response analyses of the Perry reactor building.

(vi) Plant visit and inspection.

<u>Effect of January 31, 1986 earthquake on structures</u>

The characteristics of the recorded motions on the foundations of the reactor building and the auxiliary building are judged to be similar in frequency content to the free-field ground motion. The phenomenon which could lead to different foundation motion compared to the free-field is soil-structure interaction/structure response. All category I structures except the diesel generator building and the off-gas building are founded on very stiff rock (shear wave velocity of 4900 ft/sec) or fill concrete of similar shear wave velocity. These very stiff materials are generally thought to preclude significant soil-structure interaction effects. In addition, the reactor building was analyzed as a fixed-base structure subjected to the recorded foundation motions (three translations) and good correlation of calculated and measured in-structure response was observed. This good correlation implies that rocking of the foundation was not significant, whereas, rocking of the foundation is an important SSI phenomenon. Hence, it is judged that the recorded foundation motions are similar to the free-field ground motion in frequency content. The earthquake motion is characterized by a very short strong motion duration (less than 1 sec) and significant frequency content at high frequencies (near 20 Hz).

There is a vast literature which documents the low damage potential of earthquakes of short duration and high frequencies. One of the most recent investigations was that of Kennedy et al. (Ref. 4). This investigation sought scale factors by which earthquake records must be scaled to induce specified levels of nonlinear deformation. Two levels of nonlinear deformation were considered, as defined by ductility ratios of 1.85 and 4.27 A ductility level of about 1.85 represents a best estimate of the inelastic deformations which would occur in a shear wall designed for static lateral loads to the ACI-349 code capacity (Ref. 4). Representative stiff structures of fundamental frequencies ranging from 2.14 Hz. to 8.54 Hz. were considered. Recorded ground motions of varying frequency content and duration were considered. None had as short a duration or as high a high frequency content as that recorded at Perry. Two records of short duration and somewhat higher frequency content (although still less than 10 Hz.) were the Gavilan College, Hollister, 1974 record and the Melendy Ranch Barn, Bear Valley, 1972 record. For a structure of fundamental frequency of 3.20 Hz. (near that of the Perry reactor building), the two recorded motions would need to be scaled by factors of 1.6 to 2.2 to achieve deformations corresponding to the design level forces. Alternatively, a measure of the effective peak ground acceleration of these records would be the instrumental peak divided by these factors. If a similar procedure were applied to the recorded foundation motions at Perry, the scale factors are expected to be significantly higher than 2 and, consequently, a measure of the effective peak ground acceleration of the Perry motions would be perhaps 1/3 of the instrumental peak acceleration or less. Excitations of this type have limited energy and, hence, little damage potential.

Soil-Structure Interaction and Structure Response

The seismic analysis of the Perry Category I structures involved developing mathematical models of their dynamic behavior and analyzing them for the design ground motion. The ability of these models to predict response from the January 31, 1986 earthquake was investigated. To do so, Refs. 1 and 2 and a tape containing the recorded acceleration time histories on the reactor building foundation were utilized. The following steps were performed.

1. Reference 1 was reviewed wherein the utility itemized a frequency and mode shape of the containment vessel near 18 Hz. and with a significant modal participation factor. The argument was made that this mode amplified the free-field motion to obtain the measured record in the containment vessel. This model included soil springs, which although stiff, raised the question of their importance.

2. Reference 2 was reviewed and the reactor building dynamic model implemented on the LLNL computer system. Frequencies and mode shapes were extracted for this model which included soil springs and checked with those of the utility.

3. A fixed-base eigenvalue extraction was performed on the model and the modes interrogated to determine

whether a mode of frequency near 20 Hz. had high importance to response of the containment vessel at a location near the recording. Such modes do exist in both the N-S and E-W directions and they are the second most important modes for the containment vessel's response.

4. Further verification of their ability to amplify the recorded motion was derived by performing a fixed-base time history analysis using the recorded foundation acceleration time histories as input. Figure 1 compares response spectra for the recorded foundation motions and the calculated containment vessel response at approximately elevation 688'. Figure 2 shows a comparison of response spectra of the recorded motions on the foundation and on the containment vessel at elevation 686'. Figure 1 shows clearly the amplification of the 20 Hz. motion from the foundation to the point on the containment vessel. The magnitude of the amplification is less than the recorded motion, however, this preliminary analysis simply assumed a design damping value of 4% of critical which is an important factor. Also, peak spectral amplification is widely recognized to be uncertain.

Open Issues

For the diesel generator building and the off-gas building which are founded on fill rather than rock, the applicant agreed to assess the effect of the January 31, 1986 earthquake on their response.

For the reactor building, the applicant agreed to assess the effect of the January 31, 1986 earthquake on calculated structural loads. His initial assessment for the containment shell showed them to be very low and below the design basis.

5. Conclusions

The January 31, 1986 earthquake is judged to have had an insignificant effect on the Perry Nuclear Power Plant structures. Further, it is judged that the Perry seismic analysis models adequately predict the behavior of the reactor building when subjected to this event. Finally, pending resolution of the open issues, the plant design of the structures is judged to be acceptable and unaffected by the event.

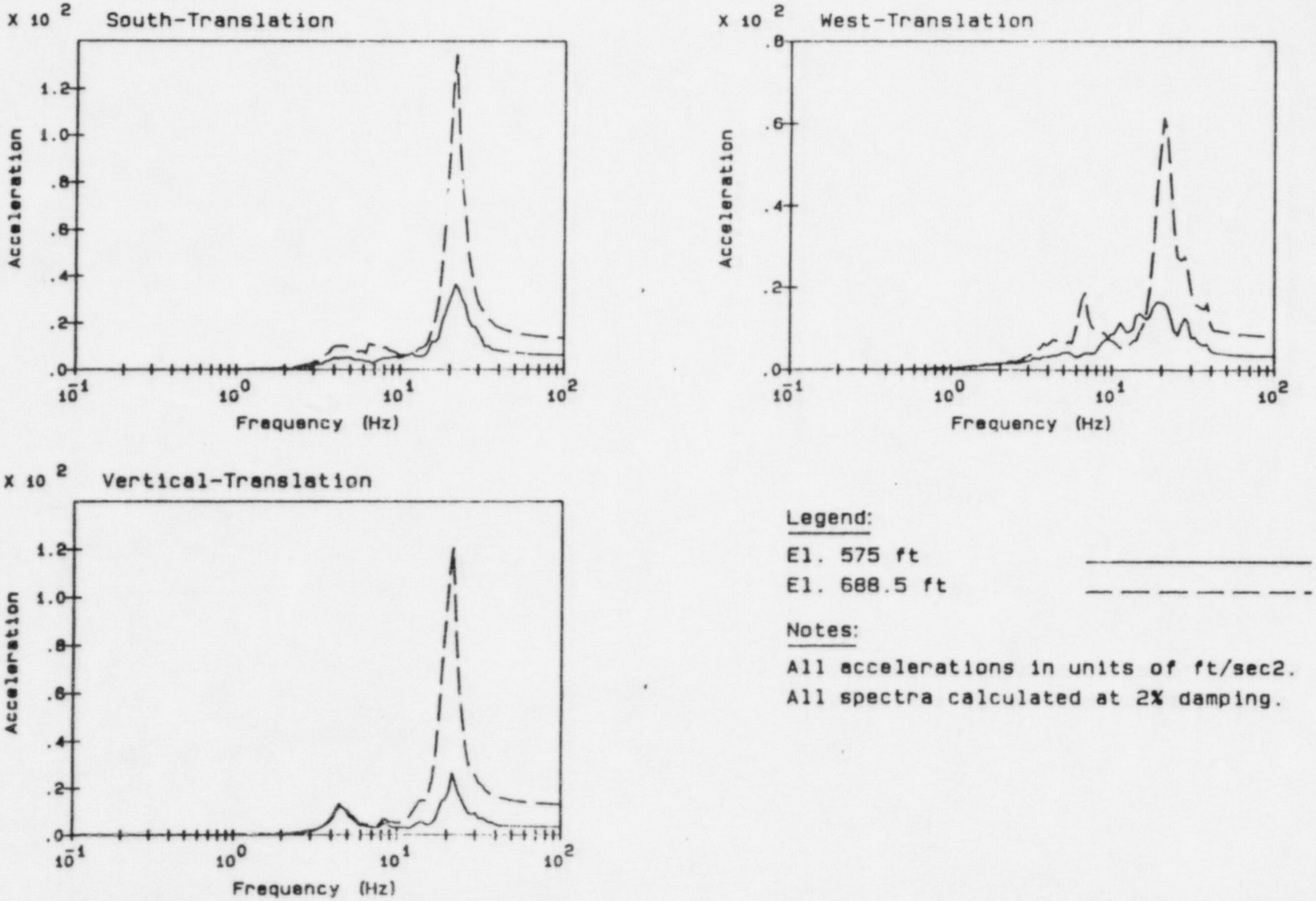

Fig. 1 Response Spectra on the Reactor Building Foundation vs. Elev. 688.5' on the Containment Vessel -- Calculated.

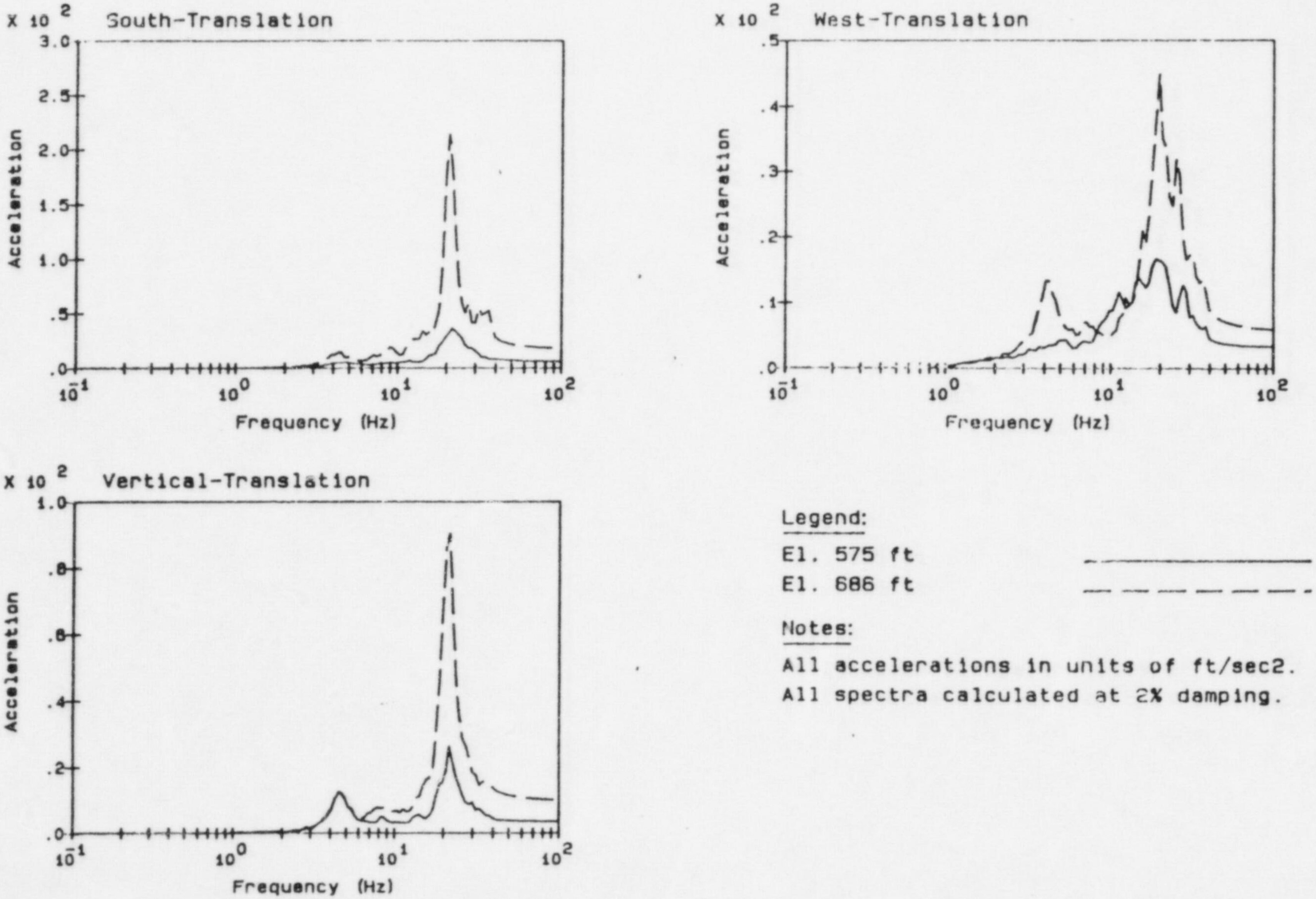

Fig. 2 Response Spectra on the Reactor Building Foundation vs. Elev. 686' on the Containment Vessel -- Measured.

REFERENCES

1. The Cleveland Electric Illuminating Co., "Seismic Event Evaluation Report, Perry Nuclear Power Plant, Docket Nos. 50-440; 50-441," February 1986.

2. Gilbert/Commonwealth, "SAP IV Input and Output Listing - Perry Reactor Building Updated Seismic Analysis," Received February 17, 1986.

3. The Cleveland Electric Illuminating Co., "Seismic Event Evaluation, Technical Presentation, February 11, 1986," presented at the Perry Nuclear Power Plant, February 11, 1986.

4. Kennedy, R. P., Short, S. A., Merz, K. L., Tokarz, F. J., Idriss, I. M., Power, M. S., and Sadigh, K. (1984), "Engineering Characterization of Ground Motion, Task I: Effects of Characteristics of Free-Field Motion on Structural Response," NUREG/CR-3805, Vol. 1, Prepared for U.S. Nuclear Regulatory Commission.