GROUND VIBRATION MEASUREMENTS NEAR THE SITE OF THE PROPOSED ANL LIGHT SYNCHROTRON RADIATION FACILITY

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SUMMARY

Ground surface vibration measurements were conducted near the site of the proposed Light Source Radiation Facility in December, 1985 and early January, 1986 during "busy" and "quiet" periods of site activity. The preliminary analysis of the measurements indicates that ground vibrations (in the vertical) observed at the site are usually at frequencies below 800 Hz. There were vibrations detected in acceleration spectra at several frequency bands between about 100 and 800 Hz, but the ground displacements associated with these frequencies were undetectable in displacement spectra.

Maximum detected displacements occurred at a frequency of about 0.2 Hz, a frequency usually associated with microseismic activity, and had rms values of about 0.7 microns. Between 1 and 10 Hz, rms ground displacements during busy periods ranged from about 0.1 to 0.025 microns. For frequencies between about 10 and 30 Hz (natural ground displacements were not detected in displacement spectra at frequencies greater than about 30 Hz), natural ground vibrations during busy periods (though without a discernible local sources) had rms displacements less than 0.01 microns. Natural ground displacements, estimated from acceleration spectra, at frequencies greater than 200 Hz were found to be less than 0.001 microns and to decrease as frequency increased. Natural rms displacements during quite periods were found to be less than during the busy periods indicated above.

Discernible local vibration sources were found to produce measurable vertical displacements. Maximum displacements were produced by large trucks passing within about 20 m of the sensor. Rms ground displacements from the large trucks ranged from about 2.0 microns at 4 Hz to about 0.003 microns at 140 Hz. Excavation activities at the A^2R^2 site produced maximum vibrations at about 10 Hz with rms displacements of about 0.02 microns.

OBJECTIVES

This preliminary reconnaissance study was undertaken at the request of the Light Source Project to determine if ambient or site cultural ground vibrations might present an operational problem for the proposed Light Source Radiation Facility. Of prime concern to the machine designers are vibrations with frequencies greater than 10 Hz. Vibrations at such a facility are important because beam-focusing mechanisms must be designed to compensate for interfering vibrations. Ground vibrations due to ambient sources are one component of the driving force for vibrations of the light source building and the machine itself. Other sources include wind loads on the structure and facility "cultural" noise due to pumps and machinery. Since the facility is not constructed, only the natural ground surface vibrations can be determined at this time. It is useful to determine whether they represent a significant driving force for vibrations in the proposed structure. Therefore, the primary objective of the study was to determine the principal frequencies of ground vibration and associated ground displacements at the site under normal site (ANL) operating conditions.

MEASUREMENT METHODS AND EQUIPMENT

The necessity to mobilize rapidly for the study limited the choice of instruments to those that could be procured quickly. In addition, an unusually cold December required that measurements be conducted in outdoor temperatures below operating specifications of some of the leased instruments and created a few experimental problems.

Two types of instruments were obtained for the study, a signal analyzer to determine frequencies and a vibration monitor to determine displacements. The signal analyzer and associated equipment was leased, and the vibration monitor was borrowed from the Baltimore District of the Corps of Engineers. All the measurements were conducted with the leased equipment because the vibration monitor arrived at ANL inoperable.

The leased equipment included a Hewlett Packard Model 3561A Dynamic Signal Analyzer, a Brüel and Kjaer (B&K) Type 2365 Charge Amplifier, and a B&K 4370 Accelerometer. The accelerometer was capable of measuring vibrations from 0.1 Hz to 5 kHz, and the signal analyzer was capable of analyzing frequencies from 125 μHz to 100 kHz.

The accelerometer was mounted vertically on a metal stake (≈0.6 m) that was driven into the ground at the measurement site such that only the accelerometer was above ground (≈0.05 m). The signal wire from the accelerometer was looped around a piece of foam, and the foam was taped to the stake to prevent wire vibrations from influencing the measurements. To insulate the accelerometer from air vibrations, a wooden box (≈0.6 × 0.6 × 0.6 m) was packed with foam with a hole cut in the foam for the accelerometer to occupy. The box was placed over the accelerometer and secured with two 18 kg (40 lb) lead bricks on top. The signal cable ran about 0.5 m to an insulated cooler where it attached to the charge amplifier. The cooler also contained an auto battery (continuously charged from an extension cord connected to a battery charger in the trailer) connected to an auto light bulb to heat the interior of the cooler and thus keep the amplifier at operating temperature. The signal from the amplifier was fed through a coaxial cable (≈30 m long) into the trailer to the H-P Signal Analyzer.

The charge amplifier provided the capability to generate acceleration, velocity, or displacement spectra by selecting the proper setting on the instrument. The amplifier characteristics limited the determination of ground displacement spectra to frequencies less than 200 Hz, but it allowed acceleration spectra to be determined up to 5 kHz.

The H-P signal analyzer had the capability to collect, manipulate, and store data in numerous modes. The data were output to a flat-bed plotter connected to the analyzer. The mode used for this study was, generally, spectral plots (plots of frequency vs amplitude). The frequency span of the analyzer could be set by the operator to virtually any desired span up to 100 kHz. The spectra could be collected in real time or the instrument could be set to collect and store spectra at a preselected interval, thus providing the capability to collect several spectra over longer time periods while unattended.

Ground vibration frequencies at the site could be determined directly from the plots of frequency vs amplitude produced by the H-P Signal Analyzer. The magnitudes of ground displacements could be calculated from the height of the spectral peak but only over the frequency range from ≈0.2 to 200 Hz. The calculation of displacement involved utilizing manufacturer's calibration factors associated with the accelerometer coupled with calibration factors associated with the charge amplifier.

MEASUREMENTS

The vibration measurements (acceleration or displacement spectra) were conducted in December, 1985, and early January, 1986, at the site indicated in Fig. 1. Three types of measurements were conducted: reconnaissance surveys, "special event" measurements, and displacement measurements. Table 1 is a summary of the times and types of measurements. In addition, spectra were automatically recorded at a predetermined interval (usually every 2 hrs) over longer time periods (24-48 hrs) to examine the time variability of the vibrations. The analyzer was usually left to record spectra in this manner during unattended periods at night, over weekends, or holidays. Both acceleration (0-5000 Hz) and displacement (0-200 Hz) spectra were collected in the unattended mode. The "special event" measurements were conducted to ascertain vibration characteristics of transient events such as vehicles passing and excavation in the dirt pile near Bldg. 330. Some reconnaissance measurements were conducted in buildings 362, 212, and 360 to identify general building vibrations due to pumps, fans, and other cultural sources.

Initial plans had been to conduct the measurements farther from the road and from other structures; however, the need for electrical power and heat for the instruments dictated their final placement. There are no apparent geological features that suggest that the general nature of the results should depend on the specific location of the sensor.

PRELIMINARY RESULTS

Numerous spectral plots, both acceleration and displacement, were examined to determine the following summary of frequencies of vibration of the site. In general, the data indicate the following:

1. No peaks were consistently observed above about 800 Hz in the acceleration spectra collected. For example, see Fig. 2.

2. There were vibrations revealed in the acceleration spectra associated with broad bands of frequencies below 800 Hz that were usually apparent, but they diminished during very quiet periods such as late night (see Fig. 3). The source of the oscillations are probably cultural in nature (traffic, trains, aircraft, etc.)

3. A peak at 60 Hz was usually apparent in acceleration spectra and was probably caused by electrical noise.

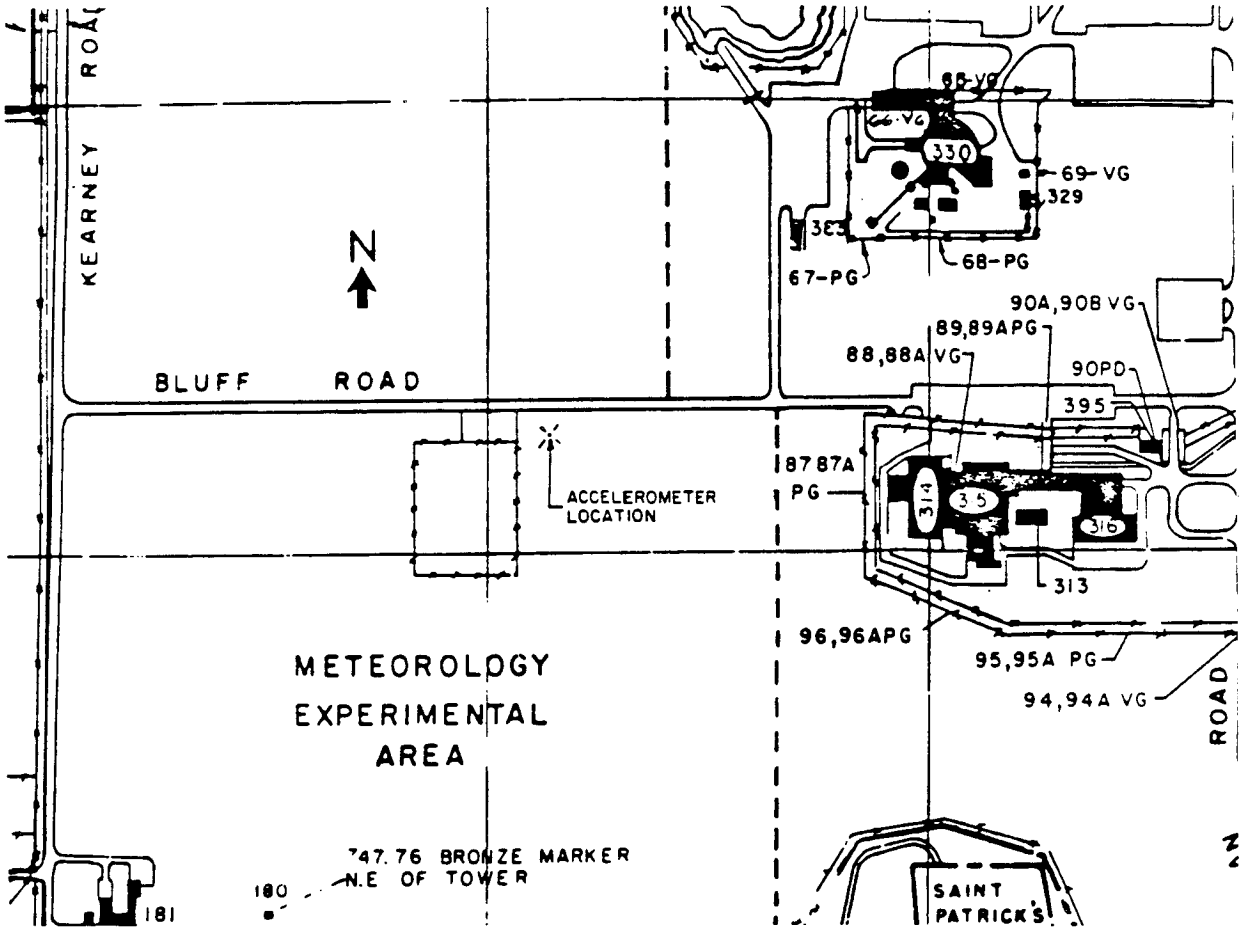

FIGURE 1 Map of Site Where Vibration Measurements were Conducted in December, 1985 and January, 1986

TABLE 1 Times of Vibration Measurements Conducted for Proposed Light Source Radiation Facility

Date(s)	Measurement	Location
12/11/85	Building/Cultural Reconnaissance	360 (IPNS)
12/13-16/85	Building/Cultural Reconnaissance	362
12/17-19/85	General Site Reconnaissance & Continuous/Interval[1]	Bluff Rd Site
12/19/85	Special Events	Bluff Rd Site
12/20-26/85	Continuous/Interval[1]	Bluff Rd Site
12/26/85	Quiet Period Displacements	Bluff Rd Site
12/26/85-1/2/86	Continuous/Interval[1]	Bluff Rd Site
1/3/86	Busy Period Displacements	Bluff Rd Site
1/10/86	Building/Cultural Reconnaissance	212

[1]Continuous/Interval -- Generally unattended measurements with analyzer set to collect a spectra each preset interval (usually 2 hrs). The instrument was usually left in this collection mode over nights, weekends, and holidays.

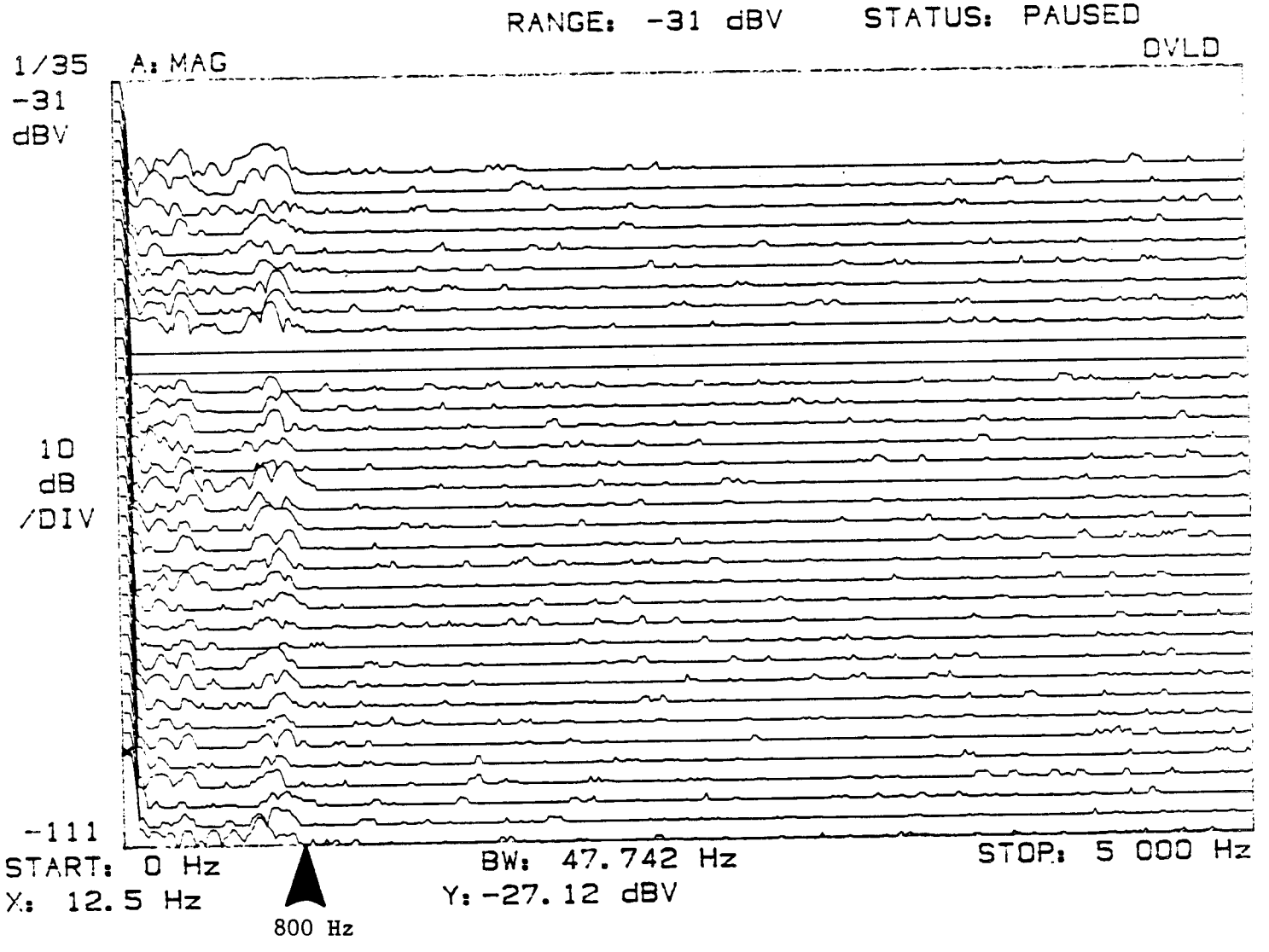

FIGURE 2 Thirty-five Acceleration Spectra Obtained at 2 hr Intervals from 1400 hrs on December 20, 1985 to about 1400 hrs on December 23, 1985 (over weekend)

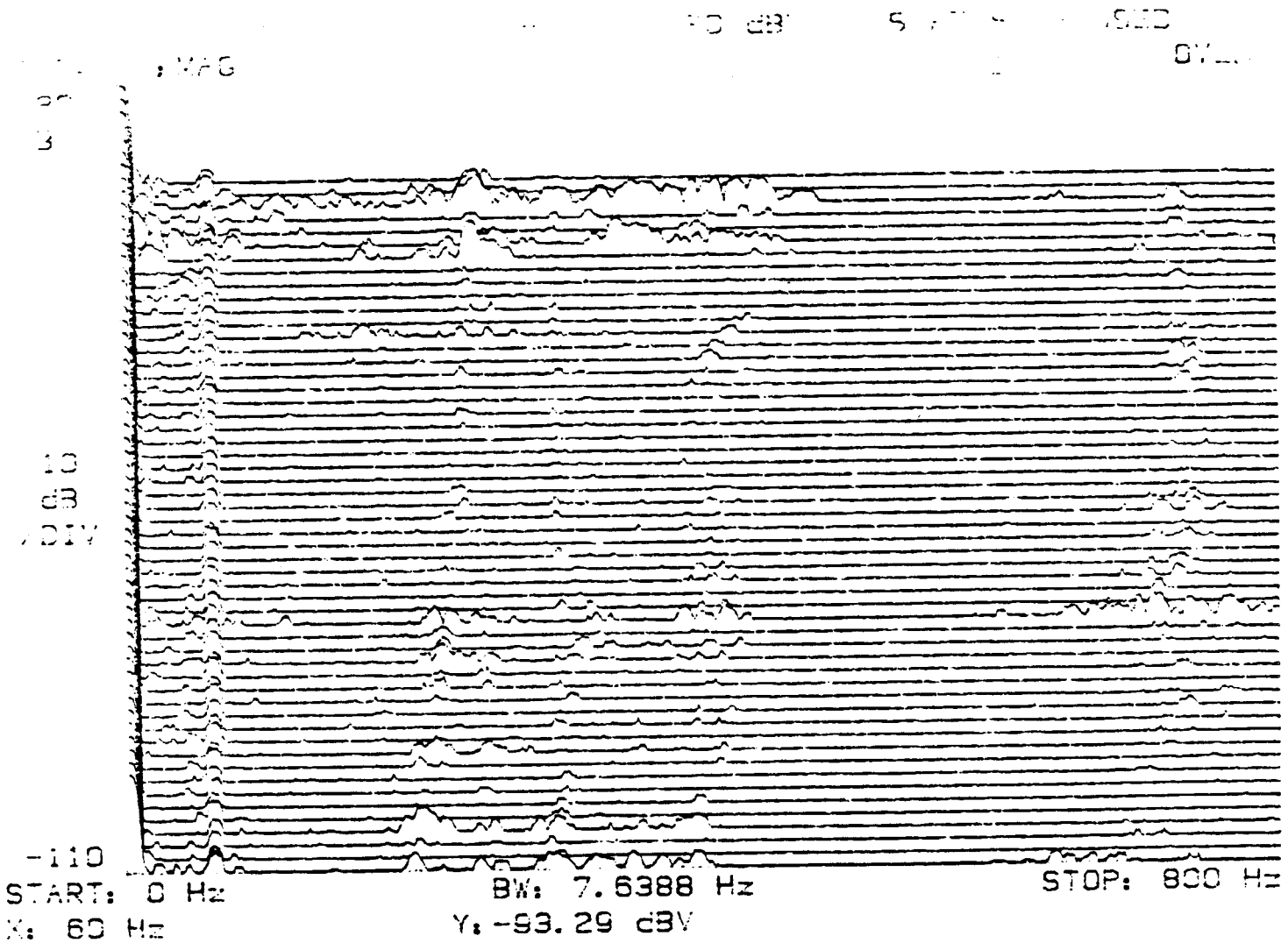

FIGURE 3 Fifty-four Acceleration Spectra in the 0-800 Hz Range Obtained at 20 Minute Intervals from 1400 hrs on December 17, 1986 to about 1000 hrs on December 18, 1986

4. Local vehicular traffic tended to create a rather broad band response that ranged from as low as about 4 Hz to as high as 150 Hz with maximum values in the range of about 20 to 50 Hz. Vehicle-to-vehicle spectral differences were apparent.

5. Excavation activities at the A^2R^2 site (about 100 m from the sensor were very apparent in both acceleration and displacement spectra at frequencies between about 7 to 20 Hz (see the displacement spectrum Fig. 4).

6. Very low frequency vibrations at less than 1 Hz (0.2-0.7 Hz) were apparent in the displacement data (see Fig. 5). These are in the range of microseismic events and may be a result of numerous cultural and natural sources such as trains, interstate highway traffic, wind oscillation of trees and structures, and waves on the Lake Michigan shore.

Displacements were determined for frequencies in the range from about 0.2 to 200 Hz (the range permitted by the amplifier) for selected natural displacement spectra. In addition, displacements for frequencies above 200 Hz were estimated from acceleration spectra. Figure 6 is a plot of the envelope of peaks of the rms displacements vs frequency over the 0.2 to 200 Hz range (no natural displacements were detected above 30 Hz) for a quiet period (December 26, 1985) and for a busy period (January 3, 1986). The magnitudes of rms displacements generally decrease with frequency, and displacements during busy periods generally exceed those during quiet periods for all frequencies. In addition, displacements were calculated for some of the special events such as traffic. Preliminary analysis of the displacement data indicate the following:

1. Maximum natural rms ground displacements occurred at a frequency of about 0.2 Hz and were about 0.7 microns during the busy period. This frequency is associated with microseismic activity and is attributed to multiple causes such as traffic, wind, and waves beating on shorelines.

2. Natural rms ground displacements in the 1 to 10 Hz range were determined to range from about 0.1 to 0.025 microns.

3. Natural rms ground displacements measured between about 10 Hz and 30 Hz were less than about 0.01 microns.

4. Large trucks passing the site (about 20 m from the sensor) produced maximum rms ground displacements of about 2.0 microns at about 4 Hz. Displacements dropped rapidly as the frequency increased to about 0.003 microns at 140 Hz.

5. Several records of "shock waves" traversing the area were recorded. A wave at approximately 10 Hz was noted in the raw data at the site. During measurements conducted on a concrete slab in Bldg. 212, several shock waves were noted at approximately 1 Hz. These shock waves were noted in the displacement record data and not in spectra, and the

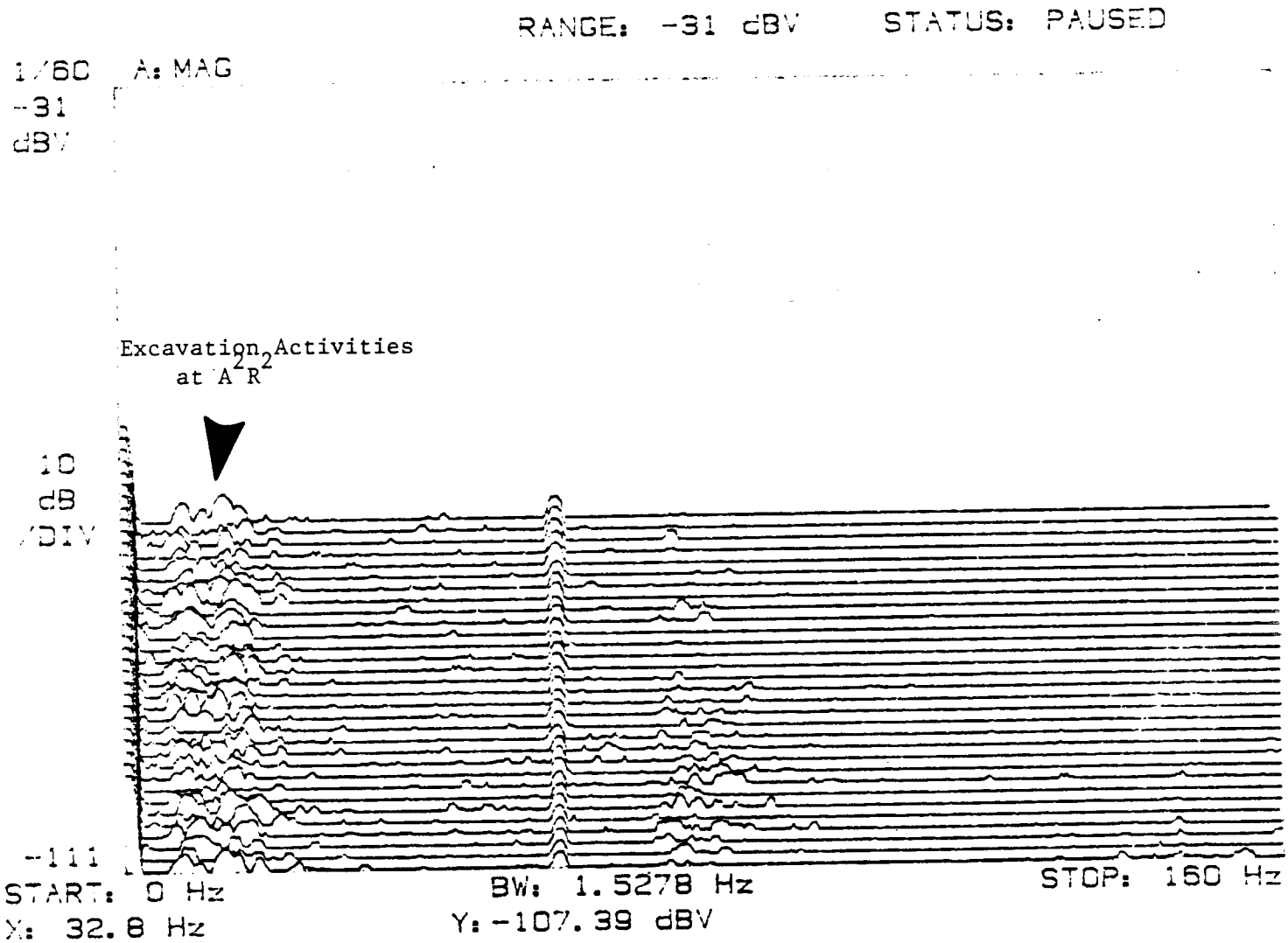

FIGURE 4 Thirty-one Displacement Spectra Obtained on December 18, 1985 Showing Vibrations from the Excavation Activities at the A^2R^2 Site Centered around 15 Hz

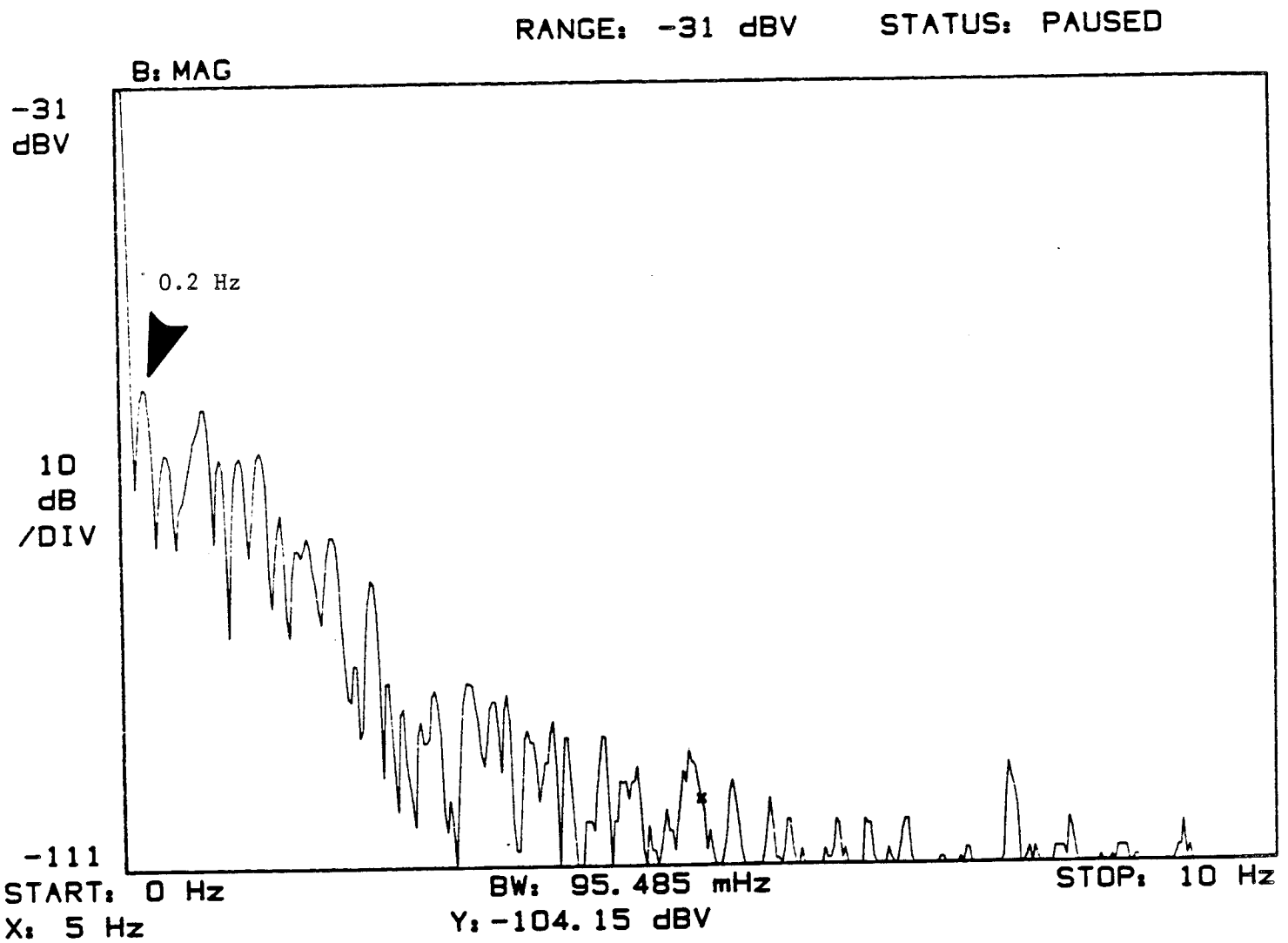

FIGURE 5 A Displacement Spectra Obtained on December 26, 1985 Indicating Peaks at the Microseismic Frequencies around 0.2–0.7 Hz

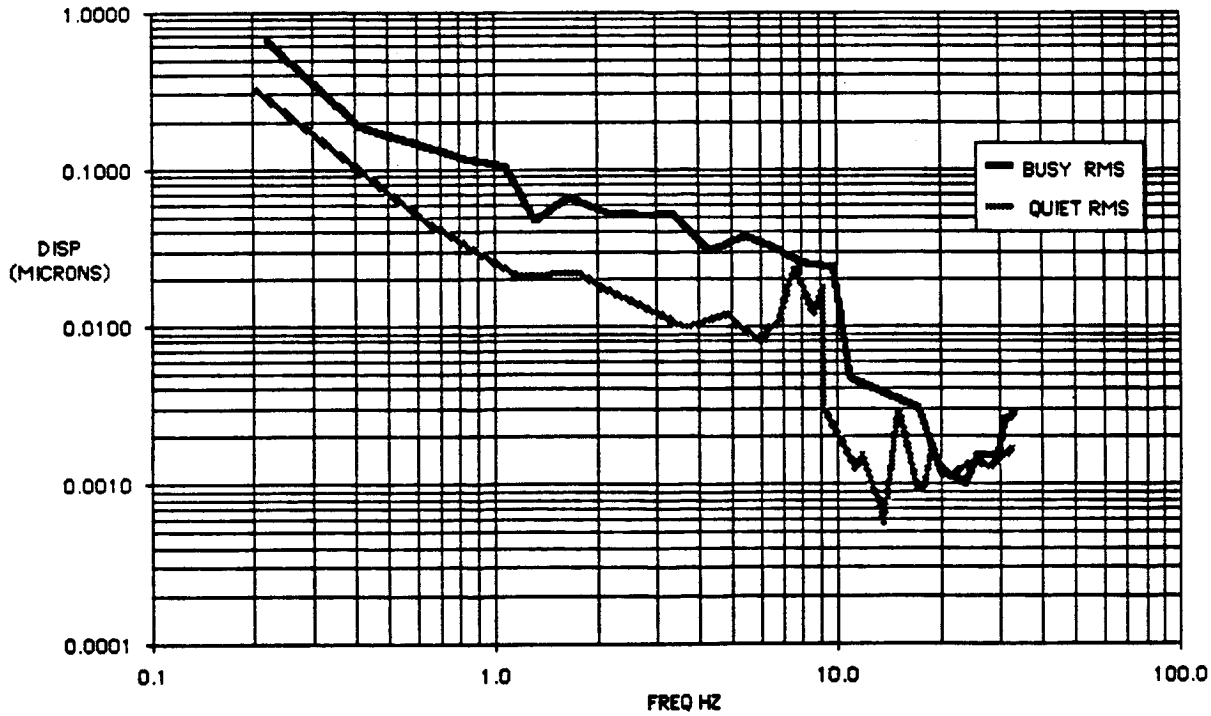

FIGURE 6 Envelope of the Peaks of Natural rms Displacements Plotted vs Frequency for a Quiet Period, December 26, 1985, and a Busy Period, January 3, 1986

displacements associated with them are estimated from that record. The displacement of the 10 Hz wave was estimated to be about 0.16 microns. Maximum (peak to trough) displacements associated with three 1 Hz waves noted in Bldg. 212 were 10, 5, and 4 microns. The source of these waves is unclear. They were not recorded by the seismograph at Loyola University, and distant earthquakes were probably not the source. They may have been shock waves from quarry blasts.

6. Natural ground displacement above 200 Hz could not be determined directly but were estimated from acceleration spectra. They were found to decrease rapidly as frequency increased and were estimated to be about 8×10^{-5}, 1×10^{-4}, and 2×10^{-5} microns at 260, 340, and 410 Hz, respectively. Thus, it appears unlikely that displacements greater than 0.001 microns would occur at frequencies higher than 200 Hz.