SITE DEPENDENT RESPONSE SPECTRA
HADDAM NECK SITE
DRAFT REPORT

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TABLE OF CONTENTS

	Page
1.0 INTRODUCTION	1
2.0 THE SITE DEPENDENT RESPONSE SPECTRA METHODOLOGY	6
3.0 EVALUATION OF THE GROUND MOTION POTENTIAL AT THE HADDAM NECK SITE	7
3.1 Introduction	7
3.2 Regional Tectonic Framework	8
3.2.1 Piedmont Atlantic Coastal Gravity Province - Site Province	9
3.2.2 Southeastern New England Platform	11
3.2.3 Western New England Fold Belt Province	13
3.2.4 Northeastern Massachusetts Thrust Fault Complex	15
3.3 Estimated Seismic Intensities at the Haddam Neck Site	16
3.4 Recommendations for Magnitude and Distance of Design Earthquake	18
3.5 Haddam Neck Site Characteristics	22
4.0 DERIVATION OF RESPONSE SPECTRA	23
4.1 Strong Motion Data Base	23
4.1.1 Data Base Search	24
4.2 Data Processing	26
4.2.1 Strong-Motion Signal Correction	26
4.2.2 Spectra Derivation	28

TABLE OF CONTENTS (CONT'D.)

	Page
4.3 Results: Seismic Response Spectra	29
5.0 CONCLUSION	34
REFERENCES	
TABLES	
FIGURES	
APPENDIX A EARTHQUAKE CATALOG	

1.0 INTRODUCTION

Seismic design values for nuclear power plants are based on two basic decisions: first, the selection of the size and location of an earthquake which represents a conservative assessment of the source of maximum vibratory motion at the site; second, a conservative assessment of the resulting ground motion at the site, considering the effects of the local geologic conditions. The second assessment is generally provided in terms of a frequency-dependent response spectrum.

Using seismic and geologic data, recent investigators (Aki, 1979; Bouchon, 1979, 1980a, b) have successfully computed expected motions at specific sites using an analytical methodology. The methodology, based on physical principles, models the total earthquake process, including the generation of seismic energy for a particular fault source configuration and dimension as well as the transmission of the seismic waves to the site.

Such state-of-the-art deterministic methods for computing ground motions are not presently applicable to most Eastern United States (EUS) sites, since many of the critical parameters associated with the majority of eastern seismic events, e.g., fault location, type, and dimension, etc., are not well known. The basic reason for this lack of information is the absence of any evidence of recent surface faulting that could be associated with the known seismicity. In contrast to the Western United States, EUS events are likely occurring at sufficient depth with no surface expression and are not apparently correlated to known surface geology. In the absence of a satisfactory explanation of the seismicity in terms of surface geology, seismic networks and geophysical mapping techniques have been implemented to study the subsurface in order to identify and ultimately quantify the seismogenic regions in terms of their seismic potential. To date, sufficient information has been accumulated to formulate several working hypotheses about the causes of seismicity in specific EUS regions, e.g., Cape Ann, Massachusetts, Ossipee, New Hampshire, New Madrid, Missouri, Attica, New York, etc.

Because the present understanding of EUS seismicity does not permit the discrimination of all active tectonic features, both with respect to past and future activity, the "tectonic province" approach, as defined by the USNRC in Appendix A, 10 CFR, Part 100, is the current method for determining the maximum ground motion potential at an EUS site.

For most applications, the tectonic province approach can be unrealistically conservative inasmuch as it assigns to every location a minimum seismic potential equal to the maximum historical earthquake. Equivalently stated, the approach assumes that active faults with dimensions sufficient to support the maximum historical event are ubiquitous throughout the region. This assumption contradicts the reality of the earthquake process which involves failures of crustal rocks along zones of weakness. The presence of weaker zones necessarily implies the coexistence of zones of strength, which indeed are observed as aseismic stable blocks. The clustering distributions of earthquakes in the EUS, as well as in other regions, support this contention.

Although the source of seismic potential for an EUS site cannot be more specifically answered than with those estimates made by application of the tectonic province methodology, the expected vibratory motion, can be more realistically addressed with a site-specific approach than with the established practice of using generalized response spectrum shapes. Current practice defines the ground motion associated with the maximum earthquake potential by a standard response spectrum shape, e.g., USAEC Regulatory Guide 1.60, scaled to a "zero period" peak ground acceleration empirically determined for a maximum intensity estimated for a site. Such practice involves questionable scaling procedures wherein strong motion records representing a wide range of magnitudes, intensities, distances, and site conditions are used to abstract a generalized spectral shape which is linearly scaled to model a wide range of seismic potentials. This procedure provides unrealistic ground motion estimates except in those few cases in which the seismic setting is similar to the average conditions represented by the data set upon which the shape was based. Thus, scaling standard response spectra shapes to model a seismic scenario which is not well represented by the original data set should be avoided whenever possible.

The site-specific approach develops response spectra based on strong motion data selected under criteria that closely model the parameters used to describe the occurrence of the maximum earthquake potential, as well as the plant site conditions. Of the various parameters available to quantify an earthquake and, more specifically, the effects of a hypothetical earthquake at a site, those determined instrumentally are more reliable than any others based on noninstrumental evaluations. For instance, the magnitude and location of an earthquake are computed from instrumental recordings. Similarly, the strong ground motions observed at specific sites are recorded on accelerographs, and the local geologic conditions at the sites can be well determined using geophysical surveys. On the other hand, the Modified Mercalli intensity at an accelerograph site is not easily evaluated and generally is assigned the intensity level prevalent in the surrounding region.

By using accelerograms selected according to three criteria, e.g., the magnitude of the event, the distance to the site, and the type of local geology, a range of expected ground motions at a site can be reasonably well established. It should be noted that many more parameters influence the resulting site ground motion. These include the fault mechanism, azimuthal directivity of the seismic wave radiation pattern, stress drop, etc. Therefore, ground motion estimates determined on the basis of only three parameters will exhibit significant scatter, which can be interpreted as a probability density function of expected motions. Consequently, the specification of the design ground motion at the site will involve choosing from the density function a probability level that adequately accommodates the uncertainty of the methodology.

The present analysis used to predict ground motions at the Haddam Neck site follows the considerations outlined above and utilizes a site-dependent response spectrum approach.

2.0 THE SITE-DEPENDENT RESPONSE SPECTRUM METHODOLOGY

The approach used to develop site-dependent response spectra for the Haddam Neck site is based on the evaluation of the seismic ground motion potential at the site, within the context of tectonic provinces and structures (10 CFR, Part 100, Appendix A), in terms of magnitude and location (distance to the site) of the maximum earthquake. Accelerograms that approximate the magnitude and distance characteristics for the maximum earthquake, that were recorded at sites similar to the Haddam Neck local site geology, are used for the computation of response spectra.

Statistical processing of the response spectra data yield spectra that typify the maximum earthquake potential. Normalization or scaling of the data to peak acceleration or peak velocity is avoided, since the statistical processing is performed on the real response spectra computed from observed time histories (accelerograms).

3.0 EVALUATION OF GROUND MOTION POTENTIAL AT THE HADDAM NECK SITE

3.1 Introduction

The results of comprehensive investigations concerning the geologic history and seismicity of Eastern North America have been compiled in recent reports entitled "Eastern United States Tectonic Structures and Provinces Significant to the Selection of a Safe Shutdown Earthquake" (Weston Geophysical Corporation, 1979a), and "Geology and Seismology, Yankee Rowe Nuclear Power Plant" (Weston Geophysical Corporation, 1979b). Other recent reports provide detailed descriptions of the seismicity data base currently maintained by Weston Geophysical. These include New York State Electric & Gas Corporation, Units 1 and 2, PSAR, 1978; Public Service Company of New Hampshire, Seabrook Station, FSAR, August 1979; and Boston Edison Company, Pilgrim Unit 2, PSAR, 1976.

Contained in these reports are the geologic, geophysical, and seismologic bases for the definition of the tectonic framework in the Eastern United States with respect to the delineation of provinces and structures and their relative levels of seismic activity. The evaluation of the seismic ground motion potential at the Haddam Neck site is based upon this definition of the tectonic framework.

3.2 Regional Tectonic Framework

Detailed information on the tectonic framework and geologic evolution of eastern North America is contained in reports previously cited in Section 3.1. Provinces located within 200 miles of the Haddam Neck site include the following:

1. Piedmont Atlantic Coastal Gravity Province (site province);
2. Southeast New England Platform;
3. Western New England Fold Belt;
4. Northeast Massachusetts Thrust Fault Complex;
5. Coastal Anticlinorium;

6. Merrimac Synclinorium;
7. Adirondack Uplift;
8. Eastern Stable Platform;
9. Appalachian Plateau;
10. Valley and Ridge.

The configuration of these provinces with respect to the Haddam Neck site and the locations of historical earthquakes are shown in Figure 1.

Discussion will be limited to a review of the tectonics and seismicity of the first four provinces listed above. Due to their proximity and their level of seismicity, these four provinces have the greatest impact on the estimation of the ground motion potential at the site. Descriptions of the remaining provinces can be found in a Weston Geophysical Corporation study (1979a).

Earthquakes with epicentral intensities greater than III or with magnitudes greater than 3.0, located within 200 miles of the site, are tabulated in Appendix A.

3.2.1 Piedmont Atlantic Coastal Gravity Province - Site Province

Seismicity within the Piedmont Atlantic Coastal Gravity Province is of a moderate level. The maximum intensity associated with historical earthquakes is VII(MM).

The seismicity of the immediate site region (50 km) is characterized as low to moderate. The majority of the events are in the III-IV(MM) intensity range with several earthquakes of Intensity V(MM) and one, that of May 16, 1791, with an Intensity VI-VII(MM) (SER-Millstone II). This earthquake, centered in the East Haddam-Moodus area of Connecticut, was originally categorized as an Intensity VIII(MM), but was reevaluated as an Intensity V-VI(MM) by Reverend Daniel Linehan, S.J. (1964). For purposes of conservatism, it is treated in this study as being an Intensity VI-VII(MM).

Geologically, this province is characterized by a Precambrian basement overlain by Early Paleozoic metamorphic rocks which are locally intruded by plutons of Paleozoic age. The province is characterized by basement rocks which are deformed into a northeast-trending fabric resulting in a northeast-trending gravity high (Figure 2). Within the area of Paleozoic metamorphic rocks, structural basins of Triassic age occur from New Jersey to Georgia. A residual mantle of weathered rock exists throughout the province.

The boundary of the province is clearly defined on the west by folds of the Valley and Ridge Province north of the James River, and by the thrust faults of the Southern

Appalachian Province south of the James River. To the east, the province continues under a blanket of coastal plain sediments. The southern boundary of the province is outside the area of this study and has not been investigated in detail. Because of the thick sequence of rocks overlying the crystalline basement in this province, the regional gravity data (due in part to the basement rock) contribute significantly to the eastern and northern boundaries. The gravity data generally correlate with and support the known regional geology.

3.2.2 Southeastern New England Platform

Seismically, the province is characterized by generally low and scattered activity (Figure 1); the largest historical intensity is V-VI(MM) which is associated with the August 8, 1847, event. Nonetheless, because the 1791 East Haddam event, which occurred in the adjacent Piedmont Atlantic Coastal Gravity Province, is so close to the province boundary, the Intensity VI-VII(MM) associated with this event is conservatively accepted as the historical maximum.

The southeastern New England Platform lies south of the North Border fault of the Boston Basin and largely consists of Late Precambrian-Early Paleozoic granitic basement, with supracrustal basins containing continental sedimentary rocks (with minor interbedded volcanic units) ranging in age from older Paleozoic in the Boston Basin to Carboniferous in the Narragansett and neighboring basins of Rhode Island and southeastern Massachusetts. The platform is slightly deformed and does not have evidence of Acadian orogenic deformation. In the Boston Basin, the sedimentary rocks have been folded and thrust-faulted from the south, with apparently thin-skinned tectonic deformation (Billings, 1976). In the southwestern part of the Narragansett Basin, in southeastern Rhode Island, deformation of the Carboniferous sedimentary rocks includes folding, metamorphism, and two episodes of east-west thrusting during the Paleozoic. In eastern Connecticut, the Precambrian rocks of the Southeastern New England Platform underlie a thin cover of pre-Silurian rocks beneath the Lake Char and Honey Hill fault surfaces. Most of the platform rocks have been affected by an Alleghenian thermal or metamorphic event, locally including granitic plutonism. The platform has not, however, been deformed internally by throughgoing crustal fault structures.

The basement offshore to the south, in the area of the Long Island Shelf (Schlee, 1977), slopes to the south and is blanketed by a seaward-thickening wedge of loosely consolidated Coastal Plain sediments of Cretaceous and Tertiary age. Based on geophysical data, Sheriden (1974) has interpreted the basement of the Southeastern New England Platform to extend roughly 100 kilometers south to the southern New England shoreline. The southwestern boundary of the province continues under Long Island where it is defined as the eastern edge of a distinct gravity high.

3.2.3 Western New England Fold Belt Province

This province is defined as a separate seismotectonic province on the basis of geologic structure, geophysical signature, and a relative lack of seismic activity (Figures 1 and 2). Seismically, the province is characterized by a low level of infrequent activity (Figure 1). Intensity V(MM) is representative of the historical upper limit of this province, even though, within the province, two earthquakes of Intensity VI have occurred. The first is the Quebec-Maine border event of June 15, 1973, associated with a seismotectonic structure, the Megantic intrusives of southeastern Quebec, one of the mafic intrusives of the White Mountain Plutonic Series. The second one, although listed as Intensity VI(MM), must be characterized by a much lower value. This earthquake, which occurred on

January 30, 1952, near Burlington, Vermont, had an extremely small felt area (50 square miles). Such a small perceptible area is certainly not typical of events characterized by an Intensity VI(MM). The probability is that this event was caused by freezing conditions as cracks were noted in the frozen ground near the Winooski River. The occurrence of cryoseisms in New England is well known; these are very small events and have no effect on the selection of design earthquakes for a tectonic province.

The geologic structures which define the province are large-scale, north-northeast-trending thrust faults and folds of Paleozoic age. Geophysically, the province is characterized in part by a pronounced north-trending gravity high in its axial region.

The eastern boundary of the Western New England Fold Belt is defined as the eastern termination of the north-south structures associated with the Bronson Hill Anticlinorium. The western boundary is placed along the limit of Paleozoic overthrusts which have been termed Logan's line or Logan's structure. On the south, the province boundary is generally located along the western edge of a pronounced gravity high associated with the Piedmont Atlantic Coastal Gravity Province where the structural features, as well as the seismicity, appear to change. The northern boundary of the province in eastern Quebec lies north of the study area.

3.2.4 Northeastern Massachusetts Thrust Fault Complex

Seismically, this province is characterized by a distinctive pattern of activity (Figure 1) which suggests that any seismic event would tend to migrate along the trend of well defined geologic structures. The largest earthquakes in the province (Intensity VIII) have been located where these northeast trends are disrupted, for example, at the mafic pluton of the White Mountain series of intrusives which is nearly in the middle of the offshore continuation of the province.

The Northeastern Massachusetts Thrust Fault Complex is readily distinguished from neighboring provinces by its high frequency of post-Acadian faulting. The complex is bounded on the northwest by the Clinton-Newbury fault, dated at Middle Permian (Public Service Company of New Hampshire, Seabrook FSAR, 1974), and is delineated on the southwest by the North Border fault of the Boston Basin. The complex narrows and ends in a southwesterly direction based on both geologic data and geophysical (aeromagnetic) signature; it can be projected for tens of miles to the east on the basis of aeromagnetic patterns. The predominant pattern of deformation in the Complex is moderately to steeply northwest-dipping thrust faulting, commonly with right-lateral, west-over-east displacements (Skehan, 1968; Dennen, 1978). The Complex is a superimposed tectonic structural feature which exhibits extreme mechanical deformation of rocks both of coastal anticlinorium affinities (Goldsmith, 1978) to the north and of Avalonian affinities to the south. The boundary between these two distinctive terranes is the Bloody Bluff fault system, the principal deep crustal fault of the complex (Nelson, 1976).

3.3 Estimated Seismic Intensities at the Haddam Neck Site

The maximum ground motions at the site, in terms of Modified Mercalli intensities, were computed using an attenuation model appropriate for the EUS. Equation 1, which is formulated on observed Modified Mercalli intensity attenuation for Central United States earthquakes (Gupta and Nuttli, 1976), was used in this analysis.

$$I(R) = I_o + 3.7 - 0.0011R - 2.7 \log R \quad (R \geq 20\text{km}) \qquad (1)$$

Table 1 lists the parameters of the largest earthquakes located in the Northeast, the distances of these events to the site, and the estimated site intensities as computed from Equation 1.

Equation 1 is formulated on intensity data observed at a variety of foundation conditions, most of which are soil sites that have experienced various degrees of local amplification, due to the impedance contrast between soil layers and the underlying baserock. Because of the manner in which Equation 1 was formulated, the predicted intensities at distance are best estimates at average foundation conditions, e.g., at sites overlain be some thickness of soils. The intensity observed on sound foundations, e.g., rock foundation, as in the case of the Haddam Neck facility, is lower than the values predicted by Equation 1, since local soil amplification is not a factor at a rock site.

The information in Table 1 indicates that the maximum intensity on average foundation conditions in the immediate vicinity of the Haddam Neck facility, is a Modified Mercalli Intensity VI-VII. On the basis of the previous discussion, the intensity at the rock foundation at the site would be lower than a Modified Mercalli Intensity VI-VII.

The worst case scenario for effects at the site from hypothetical events located in adjacent provinces is associated with an Intensity VIII earthquake located 100 km from the site at the southwest corner of the Northeast Massachusetts Thrust Fault Complex. The Haddam Neck site intensity for this hypothetical event, using Equation 1, is Modified Mercalli Intensity VI.2.

On the basis of the site intensities listed in Table 1, and also on a review of the effects associated with hypothetical events located in adjacent provinces, the maximum ground motion potential at the Haddam Neck site is specified to be an Intensity VII at the site, resulting from the maximum historical earthquake known for the site province occurring at the site (at a focal distance of 15 km).

3.4 Recommendations for Magnitude and Distance of Design Earthquake

As discussed previously, the maximum ground motion potential for the Haddam Neck site is an Intensity VII earthquake occurring at the site. For the reasons discussed in Section 1.0 of this report, and to facilitate the data base search for appropriate accelerograms, it is necessary to convert this intensity to magnitude.

Several empirical methods are available to estimate the body-wave magnitude of historical earthquakes from Modified Mercalli Intensity data. One approach is to compute the magnitude from the observed maximum intensity. This procedure is only approximate since the same intensity can be produced by earthquakes from a wide range of magnitudes, depending on the focal depth of the events and the local site amplification effects.

Another more refined approach, is to estimate magnitude from the total intensity pattern of the earthquake, rather than on the singular determination of epicentral intensity. The amount of energy released in an earthquake, which is directly related to the definition of magnitudes, is assumed to be proportional to the affected area. On this basis, empirical studies have produced formulae to estimate magnitude from perceptible areas (Nuttli and Zollweg, 1974; Nuttli et al, 1979). The magnitude of the several intensity VII earthquakes in the site province have been estimated using both techniques.

uttli and Herrmann (1978) provide the following body wave magnitude-intensity relation for earthquakes occurri in the Central United States:

$$I_o = 2.0\ m_b - 3.5 \qquad (2)$$

or conversely,

$$m_b = 0.5\ I_o + 1.75 \qquad (3)$$

Using Equation 3, an epicentral intensity VII earthquake is converted to a magnitude 5.25, or rounded to 5.3 m_b.

Next, the magnitudes of the intensity VII events in the site province, were computed from total felt areas, A_f, using Equation 4 (Nuttli et al, 1979).

$$m_{bLg} = 3.25 - 0.25 \log A_f + 0.098 (\log A_f)^2 \qquad (4)$$

where A_f = total felt area in square km

Table 2 lists these computed magnitudes.

The magnitudes evaluated from the felt areas are smaller than the magnitudes calculated by converting observed intensities into magnitudes. This suggests that observed intensities are somewhat anomalous. This effect could be due to either a shallow focal depth for the events, or more likely due to local amplification of quaternary coastal plain sediments occurring in the province or exaggeration of the historical intensities (Linehan, 1964). As noted above, the amplification effect does not apply to the rock foundation condition for the Haddam Neck site.

Although the largest earthquakes in the site province have magnitudes lower than 5.0 m_b, the historical occurrence of earthquake activity near the Haddam Neck site warrants some conservatism in the selection of the design earthquake magnitude. For this reason the mean magnitude for the maximum earthquake potential is designated to be a 5.3 m_b.

In the interest of making more records available for statistical analysis of spectral ordinates and definition of the density function of ground motion, the following criteria are defined as a range of magnitudes and distances for these events:

Magnitude Range (m_b)	Focal Distance Range (km)
5.3 (±0.5)	15 (±10)

Only accelerograms recorded on foundation conditions approximating the local site geology at Haddam Neck are accepted in the development of the site response spectrum.

Since the maximum earthquake is located near the site, parameters, such as fault orientation and mechanism could have significant effect on ground motions. No formal treatment is attempted to account for these effects. The manner in which all of the unknown parameters are accommodated is through the choice of a conservative estimation of earthquake magnitude.

3.5 Haddam Neck Site Characteristics

The Haddam site is underlain by the Monson gneiss and the Tatnic formation. In the site area, the Monson gneiss is a light grey biotite-quartz-plagioclase gneiss with local occurrences of hornblende bearing gneiss; the Tatnic formation is a biotite-muscovite schist.

A seismic survey performed by Weston Geophysical Engineers (1962) determined the compressional wave velocity of the principal overburden to be 5,300 fps. The velocity of the bedrock, which is the foundation of the Haddam Neck plant, is in the range of 11,000 to 14,000 fps. This velocity range indicates a rather competent rock. The shear wave velocity of the bedrock is estimated to be in the range of 5,000 to 7,000 fps.

4.0 DERIVATION OF RESPONSE SPECTRA

4.1 Strong Motion Data Base

United States agencies that disseminate digitized accelerograms include: California Institute of Technology (CIT), Environmental Data Services for National Oceanic and Atmospheric Administration (EDS/NOAA) and United States Geologic Survey (USGS). Weston Geophysical Corporation (WGC) strong motion data base consists of all recordings that are available by these agencies. This data base includes recordings of earthquakes that have occurred not only within the Western United States, but also in Japan, Italy, Peru, and Nicaragua.

Site characteristics of strong motion recording stations have been the object of additional research. The amount of information available on the foundation conditions of each station is highly variable. It ranges from very general descriptions to detailed information including test borings and seismic surveys which provide data on layer thicknesses, and compressional and shear wave velocities. For cases where details of recording site foundation conditions are not directly available, site foundation conditions have been estimated from available geologic maps, and where applicable, from geotechnical and geophysical data extrapolated from adjacent sites.

4.1.1 Data Base Search

The strong motion data base was searched to find all recordings with parameters matching those used to characterize the maximum earthquake potential. These parameters were defined as:

1.	Magnitude	5.3 ($\pm$0.5) m_b
2.	Distance	15 ($\pm$10) km
3.	Site Condition	Competent Foundation Bedrock with Shear Wave Velocity of 5000-7000 fps.

The search provided twenty horizontal component recordings for seven different earthquakes. Information describing the selected accelerograph sites is presented in Table 3, while the earthquake identification parameters and the peak accelerations observed at these sites are listed in Table 4.

A critical review of Tables 3 and 4 indicates that the selected strong motion data are in good agreement with the defined magnitude, distance and site conditions criteria, with only two exceptions. First, on Table 3, the site conditions at the Cedar Springs Dam Pump House are described as "Shallow gravelly alluvium over granite." The recordings obtained at that station were accepted despite that reference to alluvium, because numerous reviewers have classified the site as hard due to the shallow thickness of the overburden (Trifunac and Brady, 1975). Second, on Table 4, the distance of the Temblor No. 2 station is listed as 31 km, in excess of the established distance criterion. The two accelerograms were nonetheless included in the set because the exact distance is considered uncertain in view of the fact that the fault rupture was extensive. An alternate measure of the distance considers the nearest point of approach of the rupture; this is based on the fact that seismic energy is realeased all along the surface of dislocation. Kanamori and Jennings (1978) in their study of Parkfield accelerograms have listed 10.7 km as the distance between Temblor No. 2

and the nearest point of rupture; this distance is in agreement with the criterion. For conservatism, the longer distance of 31 km was used in Table 4.

4.2 Data Processing

The general outline of the methodology used to compute response spectra is described in the flow chart (Figure 3). As discussed previously, all recordings within the data base were not obtained from the same source. Therefore, the degree of processing performed on the chosen records is not uniform. The following sections discuss the general techniques used to generate response spectra.

4.2.1 Strong-Motion Signal Correction

The data obtained from CIT and from EDS/NOAA were already corrected for the instrument response, digitization errors, and baseline drift and were ready for the spectra-generation process. However, the Friuli accelerograms were obtained in an uncorrected form, i.e., only digitized and corrected for instrument sensitivity, scaled to g/10.

The general procedure and the computer program (EQCOR) used to correct these data are described in detail by

Trifunac (1970) and Trifunac and Lee (1973). Since publication of these reports, several advances have been made in the correction process; specifically, in the choices of the low-pass filter values (Basili and Brady, 1978). Their method requires that the pass-band of the filters for EQCOR be based on both the duration of the strong motion part of the record and length of the entire record. Previously, a standard pass-band (.07-25. Hz) was used for all records. The quality of the correction process is determined by examining the computed displacements. If long-period displacements are so large that they dominate short-period ones, the correction is considered as inadequate because these long-period waves are actually unwanted noise. If this is the case, new filters must be chosen to remove this long-period noise. The choice of the pass-band becomes more critical for short duration, strong motion signals rich in high frequencies such as the Friuli sequences. Examples of uncorrected accelerograms are presented in Figure 4. Figures 5 and 6 snow the corrected accelerograms for these records along with the computed velocity and displacement time histories.

4.2.2 Spectra Derivation

Response spectra are plots of the maximum response of a simple oscillator (one-degree of freedom) to ground acceleration as a function of the natural period and damping of the oscillator. The spectra are computed by solving the equation of motion for the oscillator:

$$x + 2\beta\omega x + \omega^2 x = -a_t$$

where: x is the relative displacement of the simple oscillator;

a_t is base (ground) acceleration at time t;

ω is the natural frequency of vibrations of the oscillator;

β is the fraction of critical damping.

The details of the derivation of the solution to this equation and the computational procedures involved are discussed by Nigam and Jennings (1968).

Examples of response spectra generated for the same records discussed in the previous section are presented in Figures 7 and 8. These are plotted at damping ratios .04 and .07. Damping ratios imply fractions of critical damping; .07 damping ratio means the system is seven percent critically damped.

4.3 Results: Seismic Response Spectra

The response spectra of the twenty horizontal components listed in Table 4 were computed for several values of critical damping. Spectra at 5% of critical damping are shown over-plotted in Figure 9. The large scatter, more than an order of magnitude, in spectral accelerations, velocity, and discplacement, observed in Figure 9, clearly demonstrates the probablistic nature of earthquake motions when defined on the basis of three parameters: magnitude, distance, and site conditions. The reason for the observed scatter is that encompassed by the general criteria is a variety of specific parameters of the earthquake sources and transmission media that are primarily responsible for the observed motion. The addition of more records according to the three criteria (magnitude, distance, and site conditions) would not necessarily reduce the scatter, but would tend to reinforce it, since additional specific parameters, such as fault orientation, dimensions, stress drop, etc., previously not included would then come into play.

The task at hand, then, is to carefully examine the specific parameters of the selected earthquakes and resulting strong motion records to establish the extent to which they typify the earthquake potential accepted for the Haddam Neck site, and then on the basis of this review, to choose an appropriate design response spectrum from the data shown in Figure 9. An evaluation of the selected accelerograms suggests that even though these data meet the criteria, they nevertheless constitute a conservative estimate of the ground motion at this EUS site. The review of the data reveals that several of the recordings were obtained from earthquakes that produced surface faulting, e.g., the Oroville Earthquake, August 1, 1975; the Parkfield Earthquake, June 28, 1966. Using these recordings to model EUS ground motion is conservative since surface faulting is not characteristic of any eastern earthquakes observed to date.

Further examination fo the specific details of the selected data reveals that the most conservative aspect of the data set is the inclusion of the Temblor records for the Parkfield earthquake. This earthquake has been extensively researched due to the high accelerations recorded near the fault. Following is a summary of some important characteristics of this earthquake.

The magnitude of the Parkfield earthquake ranges widely from 5.3m_b to 6.4M_s and is typically assigned a Richter magnitude of 5.5 or 5.6. Filson and McEvilly (1967) who examined amplitude spectra for the event suggest that there was an uncharacteristic greater attenuation of high frequencies relative to longer periods, thereby making body wave magnitude estimate low at 5.3m_b. Wu (1968) computed magnitudes of 5.8m_b and 6.4M_s for the Parkfield event; therefore, the published material defines a range of body wave magnitudes for this event of 5.3 to 5.8m_b, and a surface wave magnitude of 6.4M_s.

Analysis of the earhtquake mechanism suggests a fault rupture length of 30 km with the rupture propagating at 2.2 km/sec. towards the southeast (McEvilly et al, 1967; Filson and McEvilly, 1967). Bouchon (1979) explains that the high accelerations recorded at an accelerograph near the fault trace is the result of this fault rupture propagating toward the site. Other analyses of the observed strong motion for the Parkfield earthquake indicate high acceleration-short duration motions near the fault with rapid attenuation with distance from the fault (Cloud and Perez, 1967).

The particular characteristics of the Parkfield earthquake, including the long fault length, extensive surface rupture, and large surface wave magnitude do not represent the design earthquake recommended for the Haddam Neck site. Furthermore, the occurrence of a large ground motion resulting from the directivity effect of the fault rupture propagation is regarded as a remote probabilistic event at the Haddam Neck site, since no active faults are currently known. For these reasons, the use of the Temblor records consitutes a conservative assessment.

The amount of conservatism that results from the inclusion of the Parkfield earthquake can be evaluated by computing the mean and 84^{th} percentile peak accelerations for the data in Table 4, excluding the Temblor records. The log normal mean peak acceleration of the 18 remaining records is 74.0 cm/sec^2, a reduction of 22%, while the 84^{th} percentile peak acceleration is 107.5 cm/sec^2, a reduction of 27%.

The previous discussion illustrates the conservative aspects of the Temblor records and their effects on the computed average spectral level. On this basis, the data set is regarded to be a conservative representation of the expected ground motions at Haddam Neck. The choice of an appropriate design response spectrum considers this fact, while also taking into account the critical nature of the nuclear plant design and accomodating the uncertainty inherent in the methodology of predicting strong ground motion from small data samples.

Considering these factors, the log-normal mean response spectrum computed for the 20 accelerograms listed in Table 4, is a conservative assessment of the design response spectrum appropriate for the Haddam Neck site. Figure 10 shows the log normal mean and 84^{th} percentile response spectra for five percent critical damping. It should be noted that not all 20 components were averaged at all periods. The number of spectra averaged decreases with increasing period since each accelerogram has its own pass-band selected during the correction process (see Section 4.2.1). Table 5 shows the actual number of spectra averaged in various period ranges.

The irregular shape of the recommended design spectrum, which has a pronounced spectral gap in the period range of 0.4 to 1.2 sec., is interpreted as a statistical gap resultant from averaging a small data sample, rather than a real characteristic of spectra observed at short distance at rock sites. The inclusion of additional suitable records would tend to smooth out the peaks and troughs; therefore, the recommended design spectrum is visually smoothed as the envelope of the peaks in the log normal mean curve. Figure 11 shows the final recommended smoothed design response spectra, plotted at various levels of critical damping.

Finally, the recommended site-dependent response spectrum is compared in Figure 12 to several other specifications of response spectra for the Haddam Neck site. These include the original design spectrum at Haddam Neck, the Regulatory Guide 1.60 shape anchored to .21g, and the NUREG 0098 shape anchored to the USNRC SEP Task Plan A-40 recommendations of .21g peak acceleration for the Haddam Neck site.

5.0 CONCLUSION

It is concluded from this research that the recommended site dependent response spectra constitute a more realistic representation of the ground motion than those of the standard Regulatory Guide 1.60 and NUREG 0098 shapes, while also affording an appropriate level of conservatism required in the design of critical facilities. Figure 12 also illustrates that the original seismic design of the Haddam Neck facility is adequate and conservative.

REFERENCES

The list of references will be included in the final report.

TABLES

TABLE 1

LARGEST EARTHQUAKES IN THE NORTHEAST REGION
AND THEIR EFFECTS AT THE HADDAM NECK SITE

Year	Month	Day	Lat. (N)	Long. (W)	I_o	Distance (km)	Estimated Site Intensity	Province/Structure
1966	Feb.	5	47.6	70.1	X	705	5.2	LaMalbaie Structure
1727	Nov.	9	42.8	70.6	VII	214	4.2	Northeast Massachusetts Thrust Fault Complex
1732	Sep.	16	45.5	73.6	VIII	455	4.0	Western Quebec Seismic Zone
1737	Dec.	18	40.8	74.0	VII	146	4.7	Site Province[1]
1755	Nov.	9	42.8	70.6	VIII	226	5.1	Northeast Massachusetts Thrust Fault Complex
1774	Feb.	21	37.3	77.4	VII	626	2.5	Site Province
1791	May	16	41.5	72.5	VI-VII	2	6.0-7.0	Site Province
1840	Nov.	11	39.8	75.2	VII	294	3.7	Site Province
1875	Dec.	23	37.6	78.5	VII	670	2.3	Site Province
1884	Aug.	10	40.6	74.0	VII	159	4.6	Site Province
1927	Jun.	1	43.3	73.7	VII	182	4.4	Site Province
1931	Apr.	20	43.4	73.7	VII	235	4.0	Adirondack Uplift
1940	Dec.	24	43.8	71.3	VII	275	3.8	White Mtn. Plutonic Series
1940	Dec.	24	43.8	71.3	VII	275	3.8	White Mtn. Plutonic Series
1944	Sep.	5	44.97	74.9	VIII	433	4.1	Western Quebec Seismic Zone

[1]Site Province = Piedmont Atlantic Coast Gravity Province

TABLE 2

INTENSITY VII EARTHQUAKES WITHIN PIEDMONT
ATLANTIC COASTAL GRAVITY PROVINCE

Year	Month	Day	Lat. (N)	Long. (W)	Epicentral Intensity	Felt Area Km^2	Converted m_{bLg}
1737	12	18	40.8	74.0	VII	NA	
1774	02	21	37.3	77.4	VII	150,000	4.6
1791	05	16	41.5	72.5	VI-VII	90,000	4.4
1840	11	11	39.8	75.2	VII	NA	
1871	10	09	39.7	75.5	VII	NA	
1875	12	23	37.6	78.5	VII	130,000	4.5
1884	08	10	40.6	74.0	VII	180,000	4.6
1927	06	01	40.3	74.0	VII	8,000	3.8

TABLE 3

SITE CONDITIONS OF SELECTED ACCELEROGRAPH STATIONS

Name	Location	Instrument Type	Site Characteristics
Carroll College	Helena, Montana		Hard Rock[4]
Temblor No. 2	Parkfield, California	AR-240[1]	Serpentine and fractured ultrabasic complex[5]
Oroville Seismograph Station	Northern California	S-MD[1]	Metavolcanic Schist
Cedar Springs Allen Ranch	Southern California	AR-240[2]	Granite[2]
Cedar Springs Dam Pump House	Southern California	AR-240[2]	Shallow gravelly alluvium over granite[2]
Somplago D	Friuli, Italy	SMA-1 (.25g range, turbine level)[3]	Fractured limestone and dolomite P-vel 4300 m/sec[3]
San Rocco	Friuli, Italy	SMA-1[3]	Fissured limestone[3]

[1]World Data Center A(1979)

[2]Hudson (1971)

[3]Muzzi and Vallini (1977)

[4]Chang (1978)

[5]Silverstein (1978)

TABLE 4

ACCELEROGRAMS SELECTED TO REPRESENT MAXIMUM GROUND MOTION POTENTIAL AT THE HADDAM NECK SITE

DATE mo-day-yr	TIME-UT hr min	LOCATION/NAME	REFERENCE NUMBER	MAGNITUDE m_b	EPICENTRAL INTENSITY	DEPTH (km)	EPICENTRAL DISTANCE (km)	PEAK ACCELERATION (cm/sec²)	COMPONENT	STATION
10-31-35	18 38[1]	Helena, Mont.	B025[4]	5.4[6]	VIII[10](MM)	8.0[4]	6.6[4]	143.5[4] 142.5	NS EW	Carroll College
06-28-66	04 26[1]	Parkfield, CA	B037[4]	5.3[10]	VII[2](MM)	8.6[4]	31.0[4]	340.8[4] 264.3	S25°W N65°W	Temblor No. 2
09-12-70	14 30[1]	Southern CA	W335[4]	5.2[6]	VII[10](MM)	9.0[4]	20.8[4]	69.8[4] 54.9	S85°E S05°W	Cedar Springs Allen Ranch
-12-70	14 30[1]	Southern CA	W336[4]	5.2[6]	VII[10](MM)	9.0[4]	23.3[4]	69.4[4] 55.9	S36°W S54°E	Cedar Springs Dam. Pump House
08-01-75	20 20[2]	Northern CA	T749[5]	5.8[2]	VIII[10](MM)	15.0[2]	12.0[2]	90.6[9] 82.5	N37°E N53°W	Oroville Seismo- graph Station
09-11-76	16 31[3]	Friuli, Italy	132[3]	5.0[7]	-	9.0[8]	15.5[8]	66.6[9] 35.5	EW NS	San Rocco
09-11-76	16 31[3]	Friuli, Italy	134[3]	5.0[7]	-	9.0[8]	10.0[8]	29.8[9] 22.6	NS EW	Somplago D
09-11-76	16 35[3]	Friuli, Italy	139[3]	5.3[7]	VII[11] (MKS)	6.0[8]	14.0[8]	84.9[9] 84.2	NS EW	San Rocco
09-11-76	16 35[3]	Friuli, Italy	142[3]	5.3[7]	VII[11] (MKS)	6.0[8]	6.0[8]	53.0[9] 50.0	EW NS	Somplago D
09-15-76	03 15[3]	Friuli, Italy	153[3]	5.7[7]	VIII[11](MKS)	9.0[8]	9.0[8]	118.6[9] 59.8	EW NS	San Rocco
Mean Values Standard Deviations				5.3 .25		8.9 2.4	14.9 7.9	95.0* 148.1**		

* log-normal mean
** log-normal 84th percentile

[1] Krinitzsky and Chang (1975)
[2] World Data Center A (1979)
[3] CNEN-ENEL (1978)
[4] Chang (1978)
[5] Weston Geophysical reference number
[6] Nuttli (1979)
[7] Bulletin of the International Seismological Centre, September, 1976
[8] Muzzi and Vallini (1977)
[9] Weston Geophysical corrected accelerograms
[10] Earthquake History of the United States
[11] Prochazkova et al (1976)

TABLE 5

NUMBER OF RESPONSE SPECTRA ORDINATES
AVERAGED IN VARIOUS PERIOD RANGES

Period (sec)	Number of Response Spectra Ordinates
.04-.09	20
.91-1.0	18
1.2	14
1.6-2.0	10
2.4-7.2	8

REGIONAL TECTONIC AND SEISMOTECTONIC PROVINCES

PROVINCE BOUNDARY (DASHED LINE INDICATES RELATIVE UNCERTAINTY OF BOUNDARY)

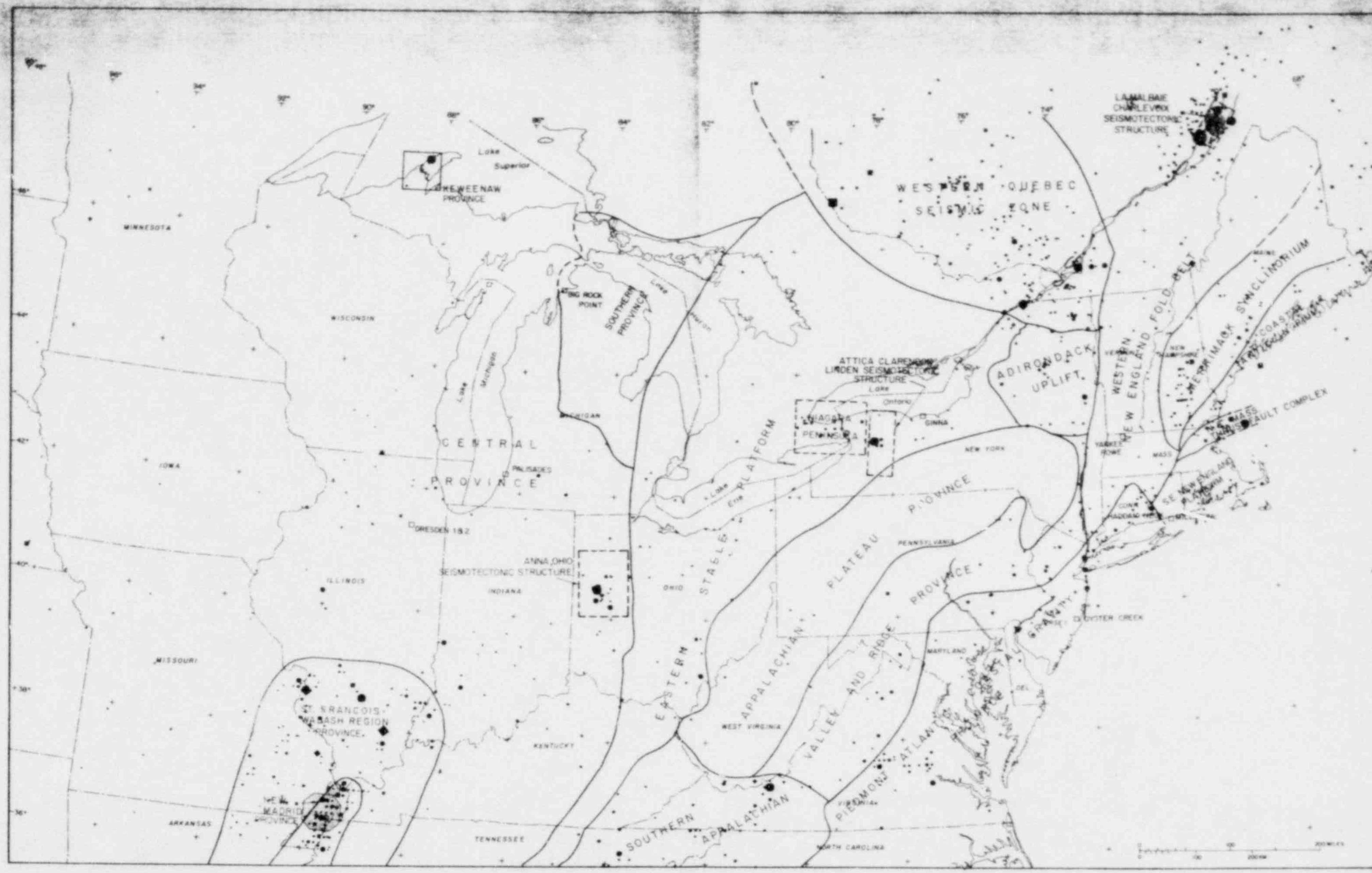
EARTHQUAKES

MAGNITUDE (1930 through 1967) / (after 1-1-68)	INTENSITY
2.0 - 3.0	IV
3.1 - 3.5	V
3.6 - 4.2	VI
4.3 - 4.7	VII
4.8 - 5.4	VIII
5.5 - 6.2	IX
6.3 - 6.7	X
6.8 - 7.2	XII

NOTE: SEISMICITY BASED ON DATA AVAILABLE AS OF JANUARY 1979.

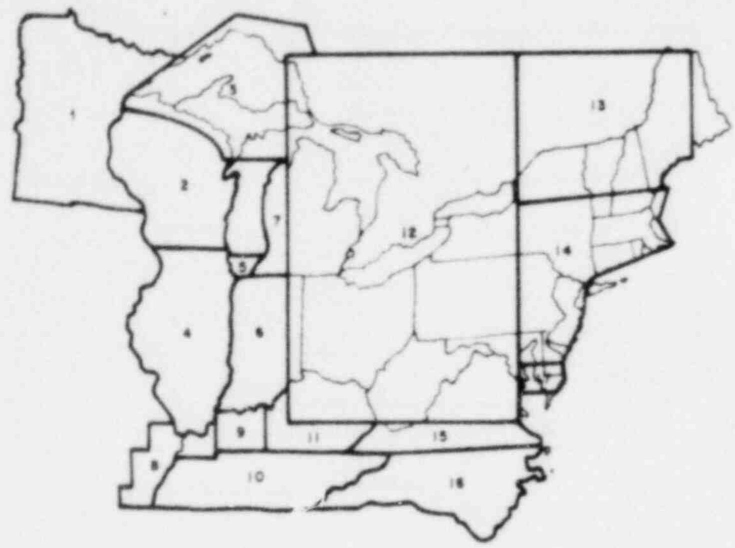
FIGURE 1

EARTHQUAKES WITH (SEISMO) TECTONIC PROVINCES/ STRUCTURES OF NORTHEASTERN AND NORTH-CENTRAL UNITED STATES.



LA MALBAIE
CHARLEVOIX
SEISMOTECTONIC
STRUCTURE
WESTERN QUEBEC
SEISMIC ZONE
KEWEENAW
PROVINCE
Lake
Superior
MINNESOTA
WISCONSIN
BIG ROCK
POINT
SOUTHERN
PROVINCE
ATTICA CLARENDON
LINDEN SEISMOTECTONIC
STRUCTURE
ADIRONDACK
UPLIFT
WESTERN
NEW ENGLAND FOLD BELT
MERRIMACK SYNCLINORIUM
COASTAL
FAULT COMPLEX
NIAGARA
PENINSULA
GINNA
NEW YORK
CENTRAL
PROVINCE
PALISADES
IOWA
DRESDEN 1&2
ANNA OHIO
SEISMOTECTONIC STRUCTURE
INDIANA
OHIO
ILLINOIS
EASTERN
STABLE
PLATFORM
PROVINCE
PLATEAU
PENNSYLVANIA
APPALACHIAN
VALLEY AND RIDGE
PROVINCE
OYSTER CREEK
MARYLAND
DEL
MISSOURI
ST. FRANCOIS-
WABASH REGION
PROVINCE
NEW
MADRID
PROVINCE
KENTUCKY
WEST VIRGINIA
PIEDMONT
ATLANTIC
ARKANSAS
TENNESSEE
SOUTHERN
APPALACHIAN
NORTH CAROLINA
VIRGINIA
YANKEE
ROWE
MASS
MAINE
NEW HAMPSHIRE
VERMONT
SE NEW ENGLAND
PLATFORM
CONN
HADDAM NECK
MICHIGAN
prepared by WESTON GEOPHYSICAL CORP

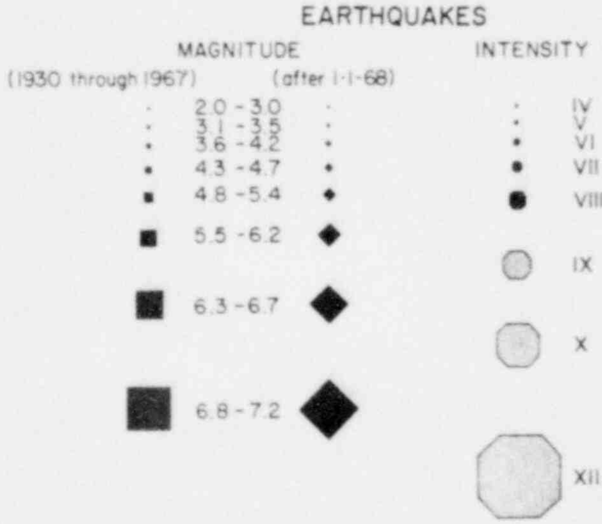
INDEX MAP OF GRAVITY DATA SOURCES



REGIONAL TECTONIC AND SEISMOTECTONIC PROVINCES

PROVINCE BOUNDARY (DASHED LINE INDICATES RELATIVE UNCERTAINTY OF BOUNDARY).

EARTHQUAKES



NOTE: SEISMICITY BASED ON DATA AVAILABLE AS OF JANUARY 1979.

GRAVITY DATA SOURCES

1. Craddock, C., H. M. Mooney, and V. Kolehmainen, 1970, Simple Bouguer Gravity Map of Minnesota and Northwestern Wisconsin, U.S. Geological Survey Miscellaneous Map Series, Map M10.
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4. McGinnis, L. D., P. E. Heigold, C. P. Erwin, and M. Heidari, 1976, "The Gravity Field and Tectonics of Illinois," Illinois State Geological Survey Circular 494.
5. O'Hara, N. W., R. J. Wold, and W. J. Hinze, 1973, "Regional Gravity and Magnetic Study of Southern Lake Michigan - Southern Lake Michigan Geophysical Study," Proceedings 16th Conf. Great Lakes Res., p. 431-440.
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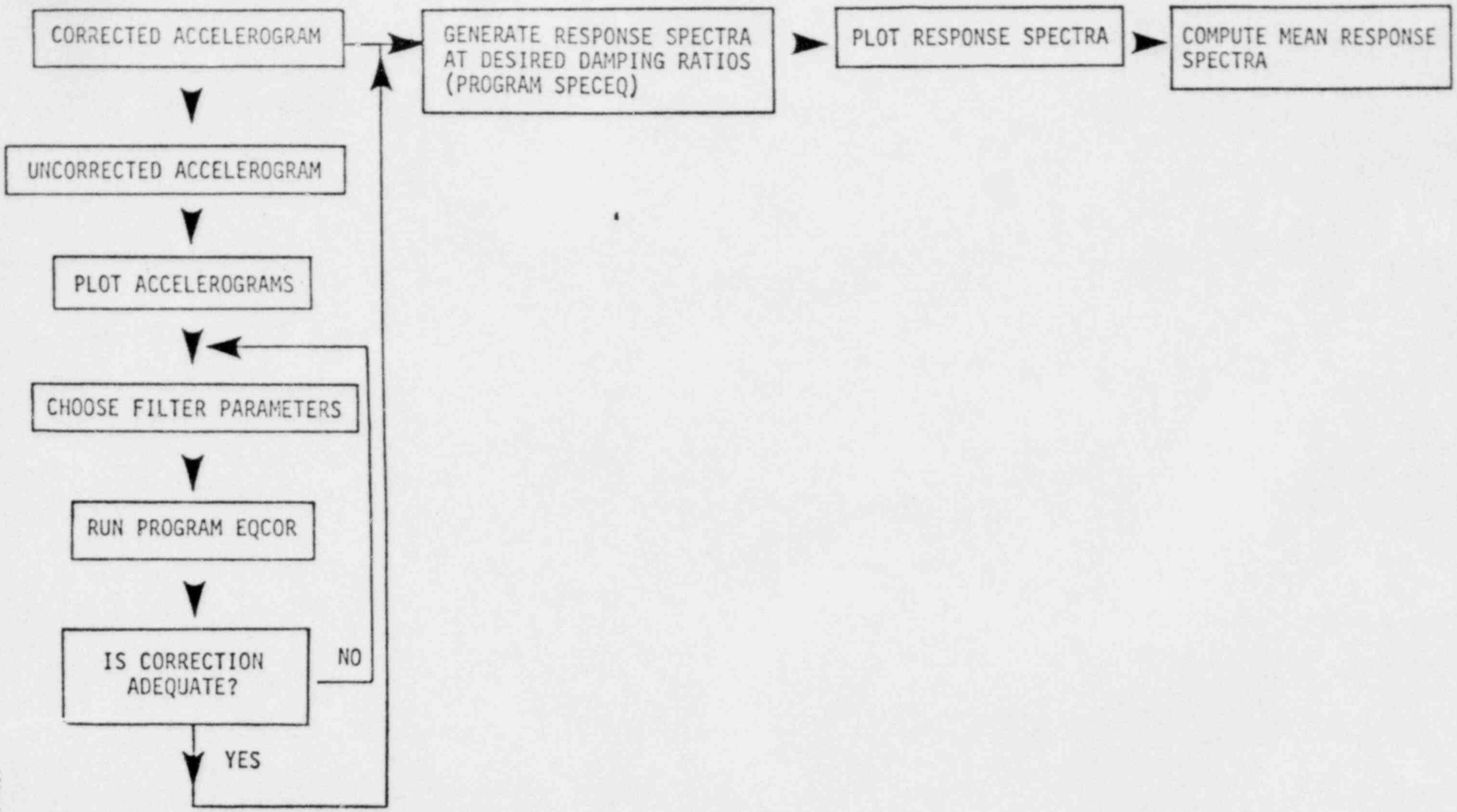
12. Weston Geophysical Corp., 1979, Gravity Map of East-Central United States and Southern Canada, compiled from numerous sources which are listed on Table 3.
13. New York State Electric & Gas Corp., 1978, New Haven PSAR, Section 2.5, Figure 2.5-27, Total Bouguer Gravity Anomaly Map.
14. Weston Geophysical Corp., 1978, Bouguer Gravity Anomaly Map of the Mid-Atlantic Region of the United States, compiled from several sources which are listed on Table 4.
15. Johnson, S. S., 1978, Gravity Map of Virginia, Simple Bouguer Anomaly, Commonwealth of Virginia, Dept. of Conservation and Economics Development, Division of Mineral Resources.
16. Mann, Virgil I., "Bouguer Gravity Map of North Carolina", Southeastern Geology, Vol. 3, No. 4, pp. 207-220, 1 map.
17. Sabet, M. A., 1977, "Gravity Anomalies Associated with Salisbury Embayment, Maryland-Southern Delaware," Geology, V. 5, No. 7, p. 433-436.

FIGURE 2

GRAVITY, AND EARTHQUAKES, WITH (SEISMO) TECTONIC PROVINCES/STRUCTURES OF NORTH-EASTERN AND NORTH-CENTRAL UNITED STATES.

prepared by WESTON GEOPHYSICAL CORP

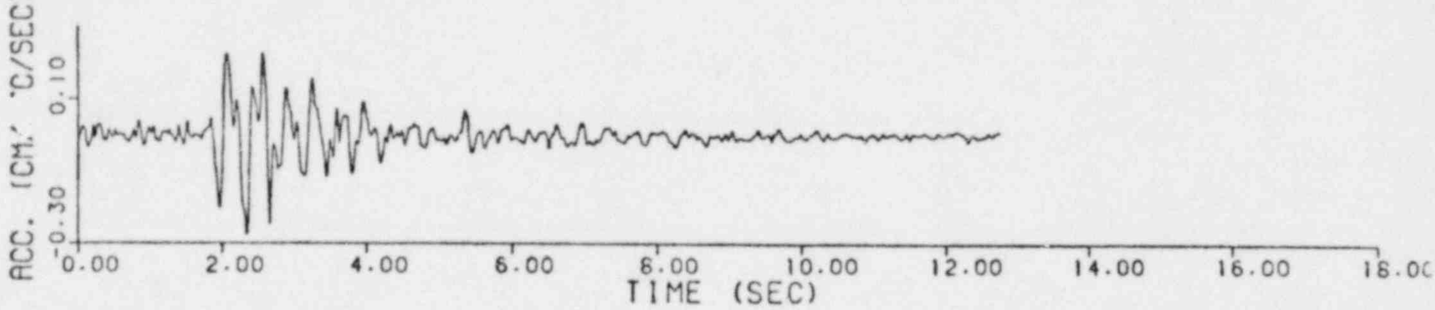


OUTLINE OF DATA PROCESSING TECHNIQUES

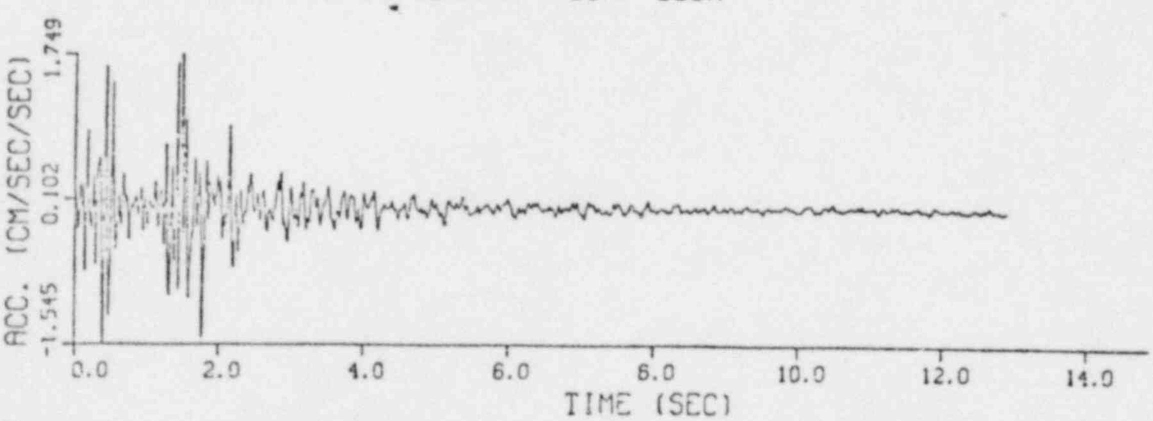
FIGURE 3

Weston Geophysical

UNCORRECTED ACCELEROGRAM
091 FRIULI EARTHQUAKE 11-JUNE-76 17H16M37
RECORDED AT TOLMEZZO COMP. NS



UNCORRECTED ACCELEROGRAM OF
OROVILLE AFTERSHOCK EARTHQUAKE 8/ 6/75- 350
MEDICAL CENTER COMP S66W



EXAMPLES OF UNCORRECTED ACCELEROGRAMS

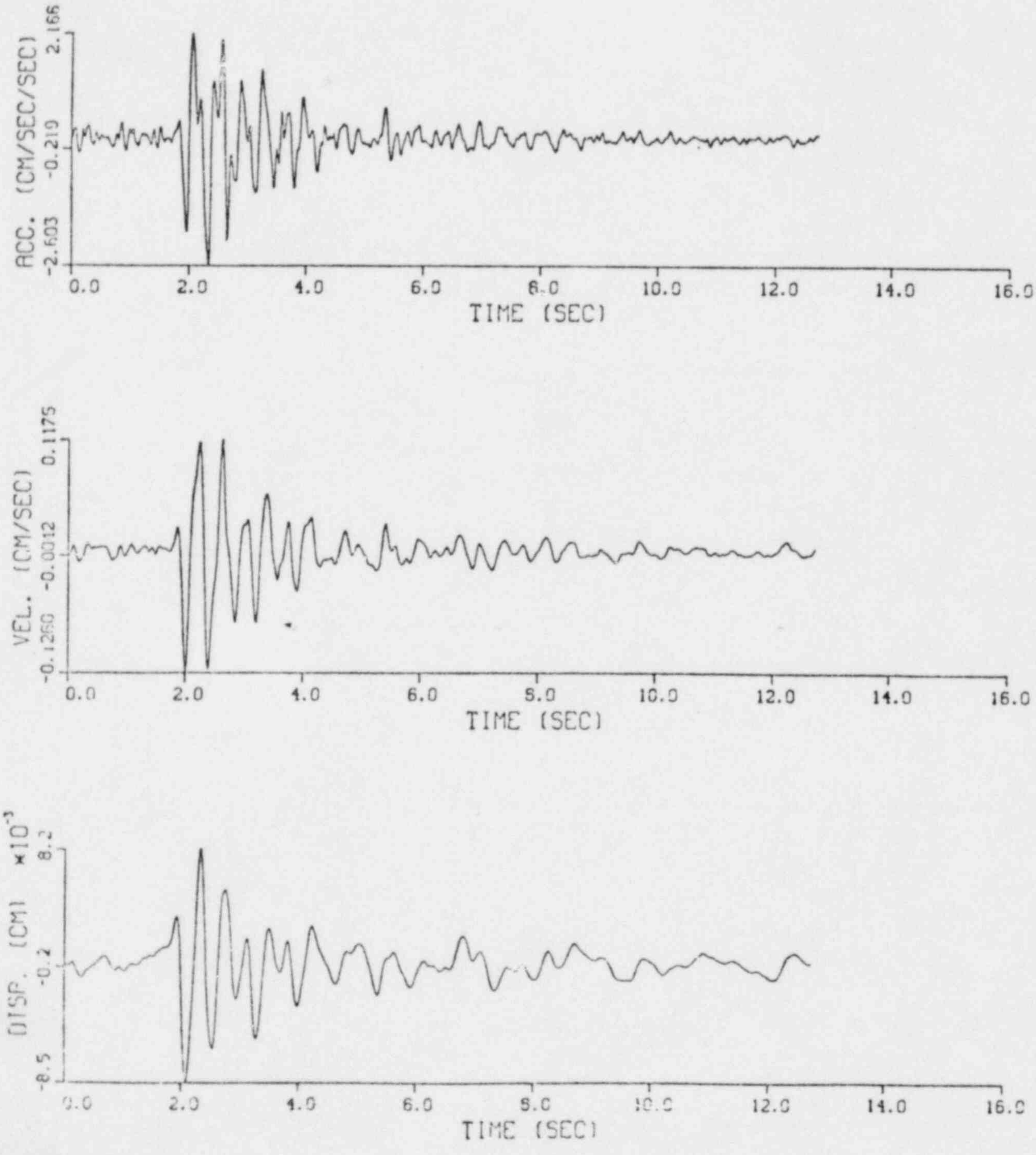
FIGURE 4

Weston Geophysical

CORRECTED ACCELEROGRAM

FRIULI EARTHQUAKE 11-JUNE-76 17H16M37

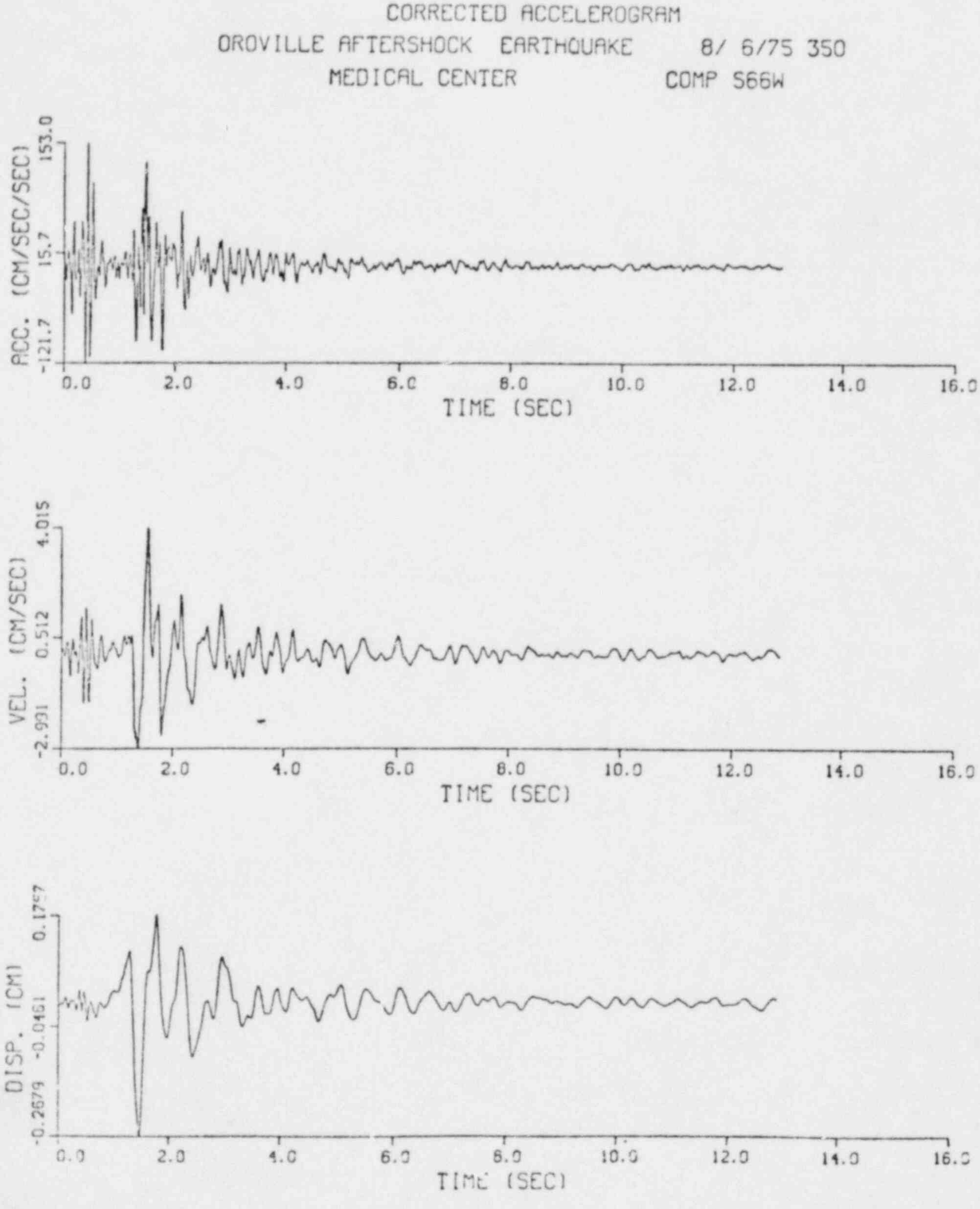
RECORDED AT TOLMEZZO COMP. NS



CORRECTED ACCELERATION, VELOCITY
AND DISPLACEMENT TIME HISTORIES

FIGURE 5

Weston Geophysical



CORRECTED ACCELERATION, VELOCITY
AND DISPLACEMENT TIME HISTORIES

FIGURE 6

Weston Geophysical

RESPONSE SPECTRA FOR

091 FRIULI EARTHQUAKE 11-JUNE-76 17H16M37S

- HORIZONTAL COMP. NS

MAG- 4.4 DIST - 13.3 km.

DAMPING RATIOS- 0.04, 0.07

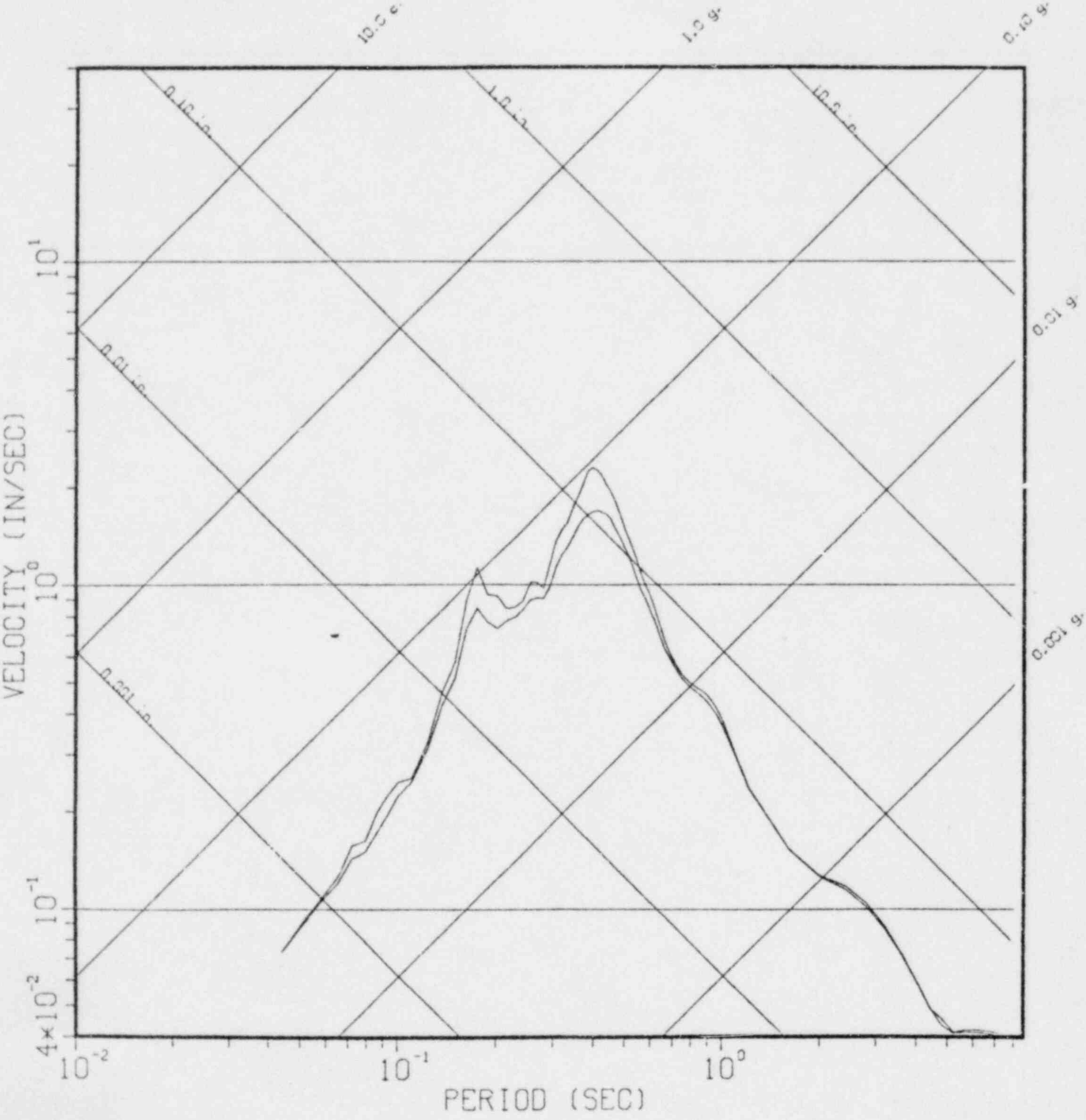


FIGURE 7

Weston Geophysical

RESPONSE SPECTRA FOR

OROVILLE AFTERSHOCK EARTHQUAKE 8/ 6/75 350 MEDICAL CENTER

- HORIZONTAL COMP S66W

MAG- 4.7 DIST - 2.1 km.

DAMPING RATIOS= 0.04, 0.07

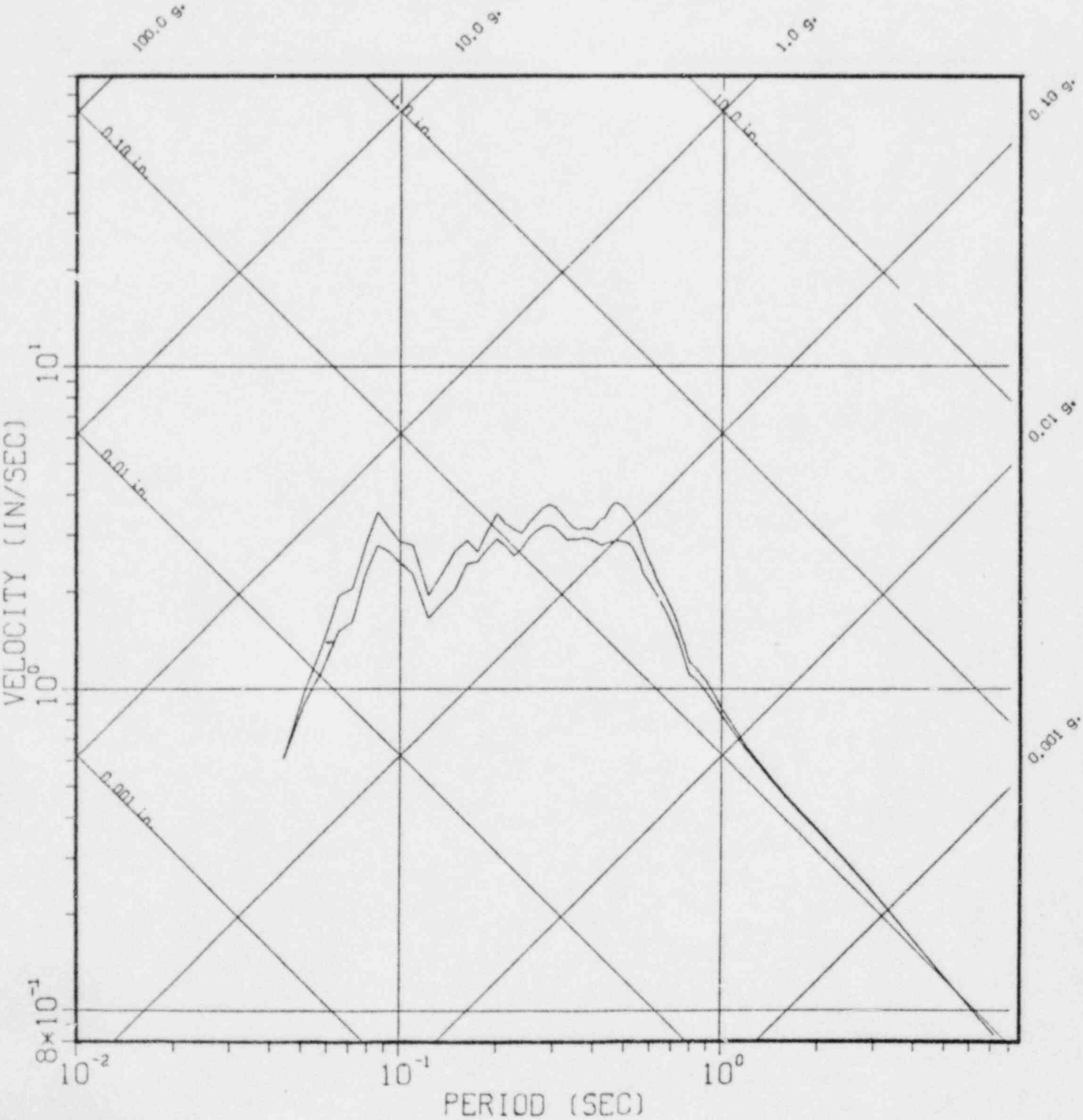
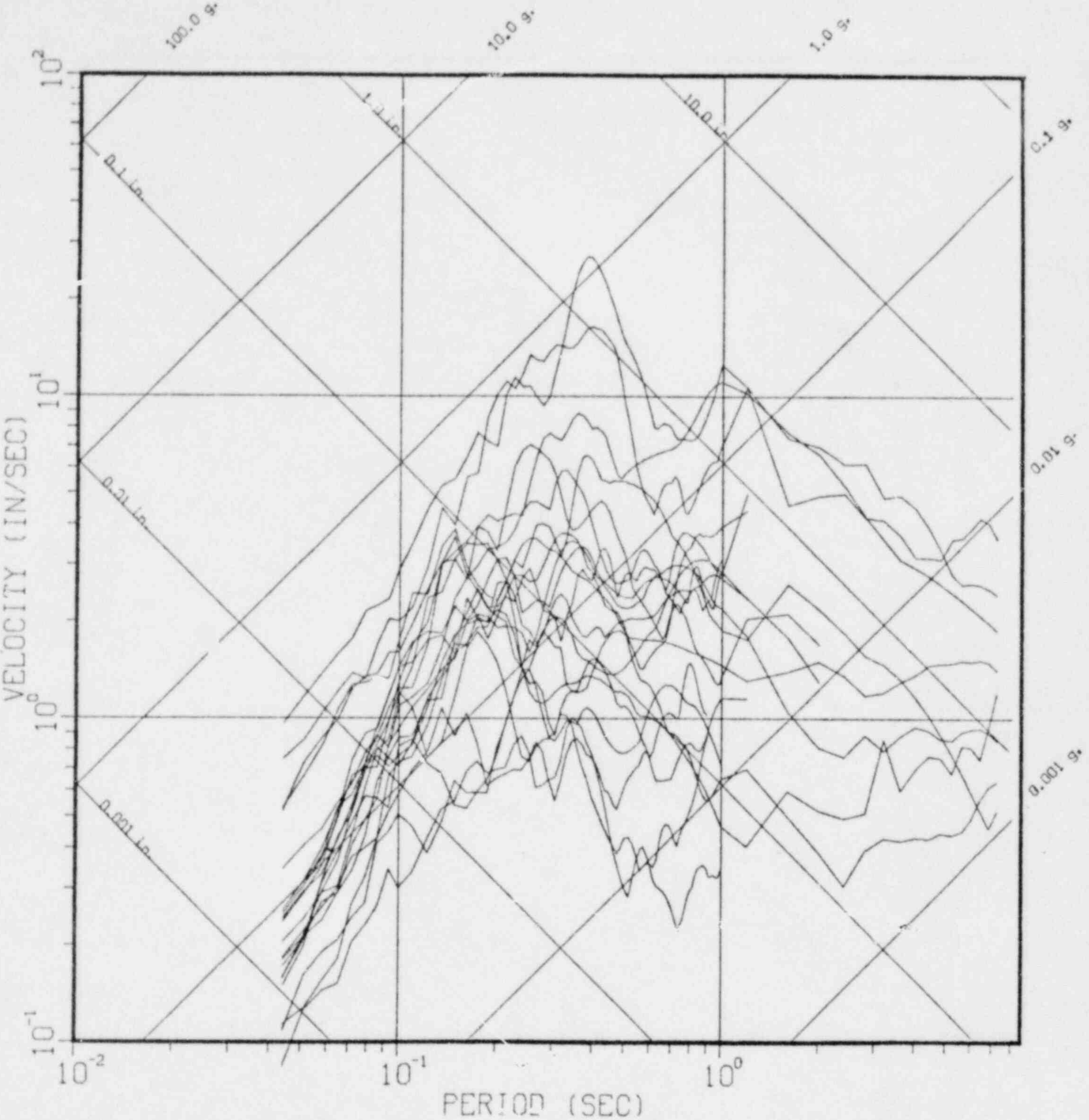


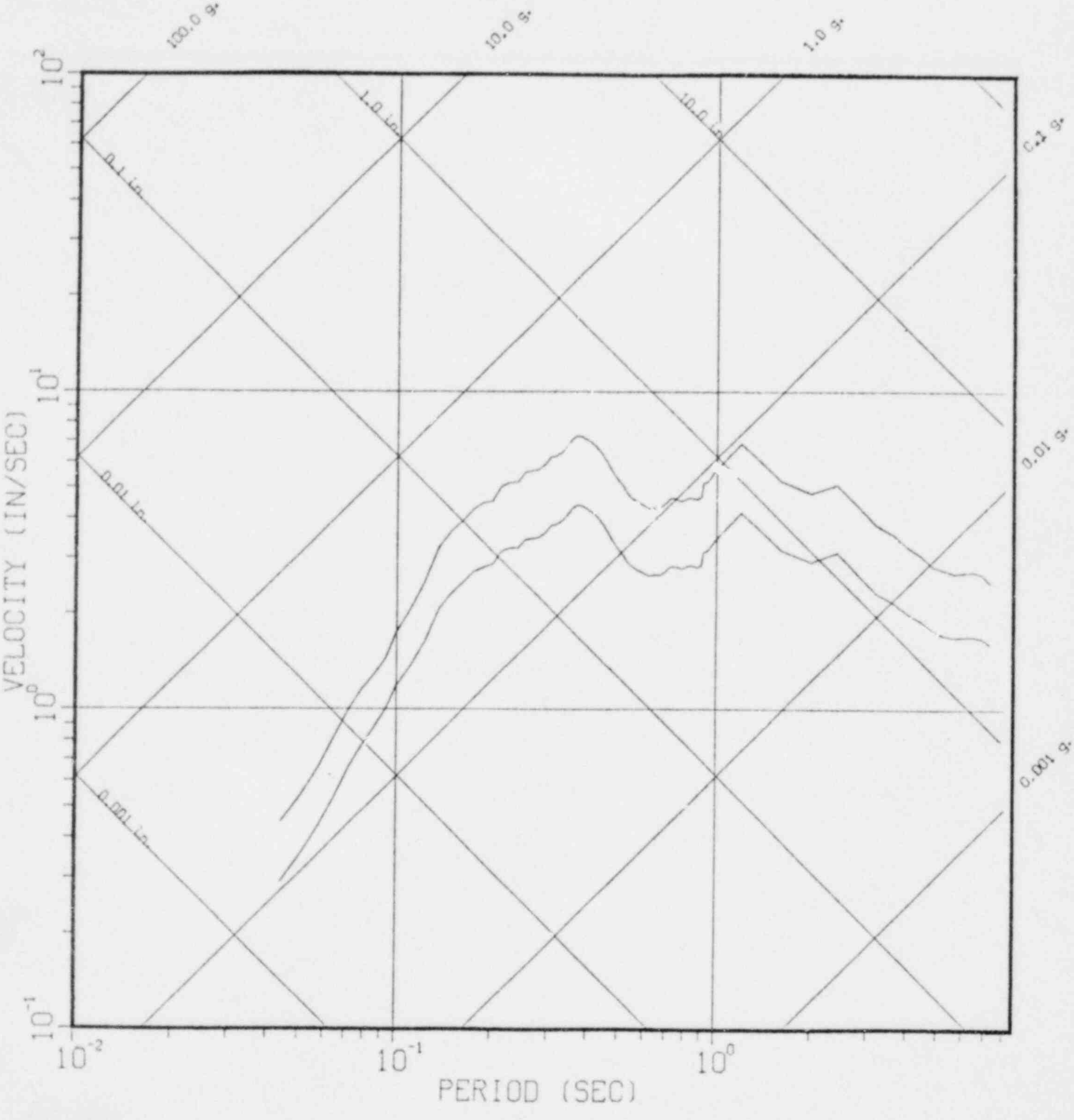
FIGURE 8
Weston Geophysical



HORIZONTAL COMPONENT RESPONSE SPECTRA
20 COMPONENTS
MEAN MAGNITUDE = 5.3 m_b
MEAN EPICENTRAL DISTANCE = 14.9 km
5% CRITICAL DAMPING

FIGURE 9

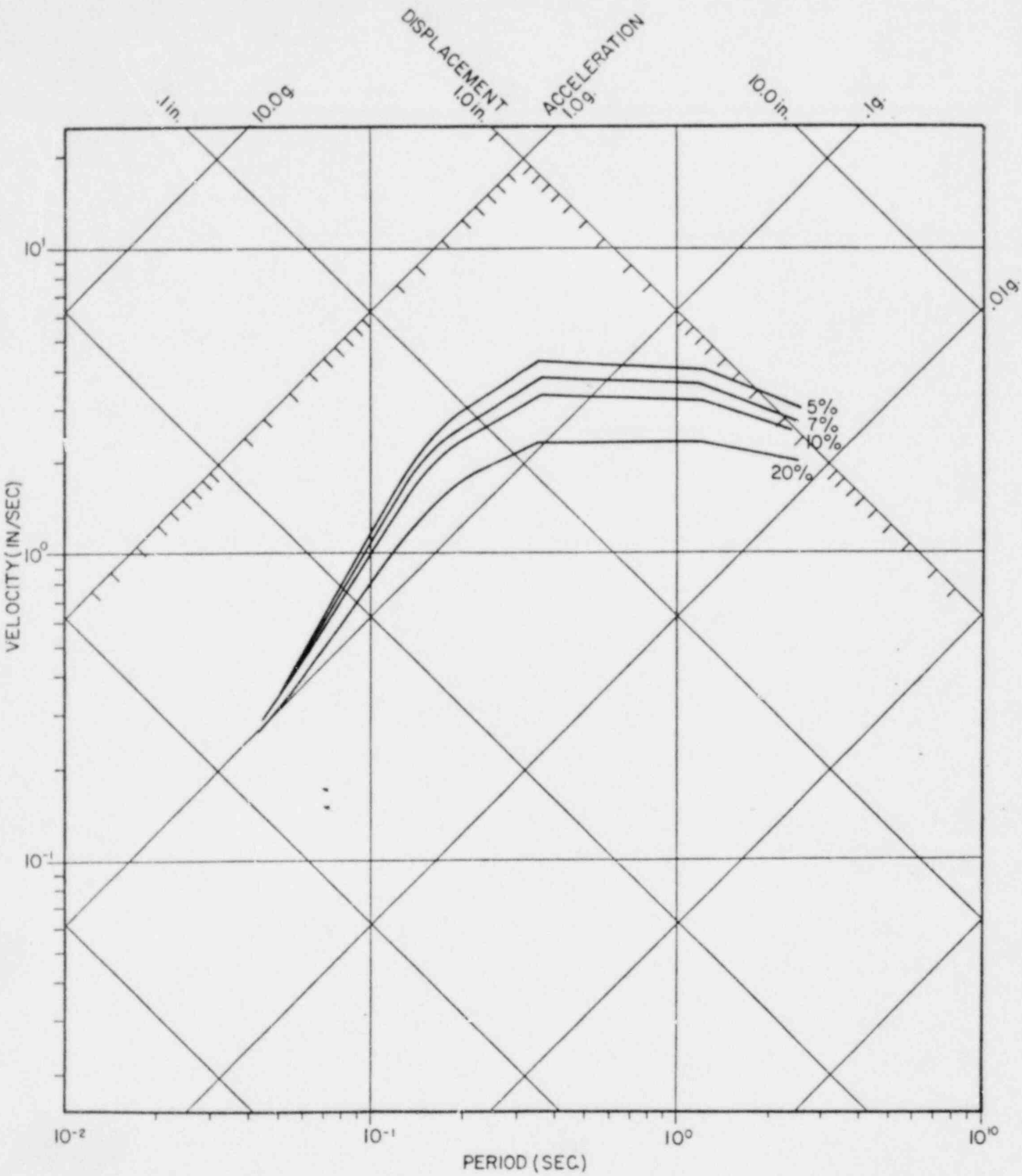
DRAFT



HORIZONTAL SEISMIC DESIGN SPECTRA
MEAN AND 84th PERCENTILE SPECTRA
5% CRITICAL DAMPING

FIGURE 10

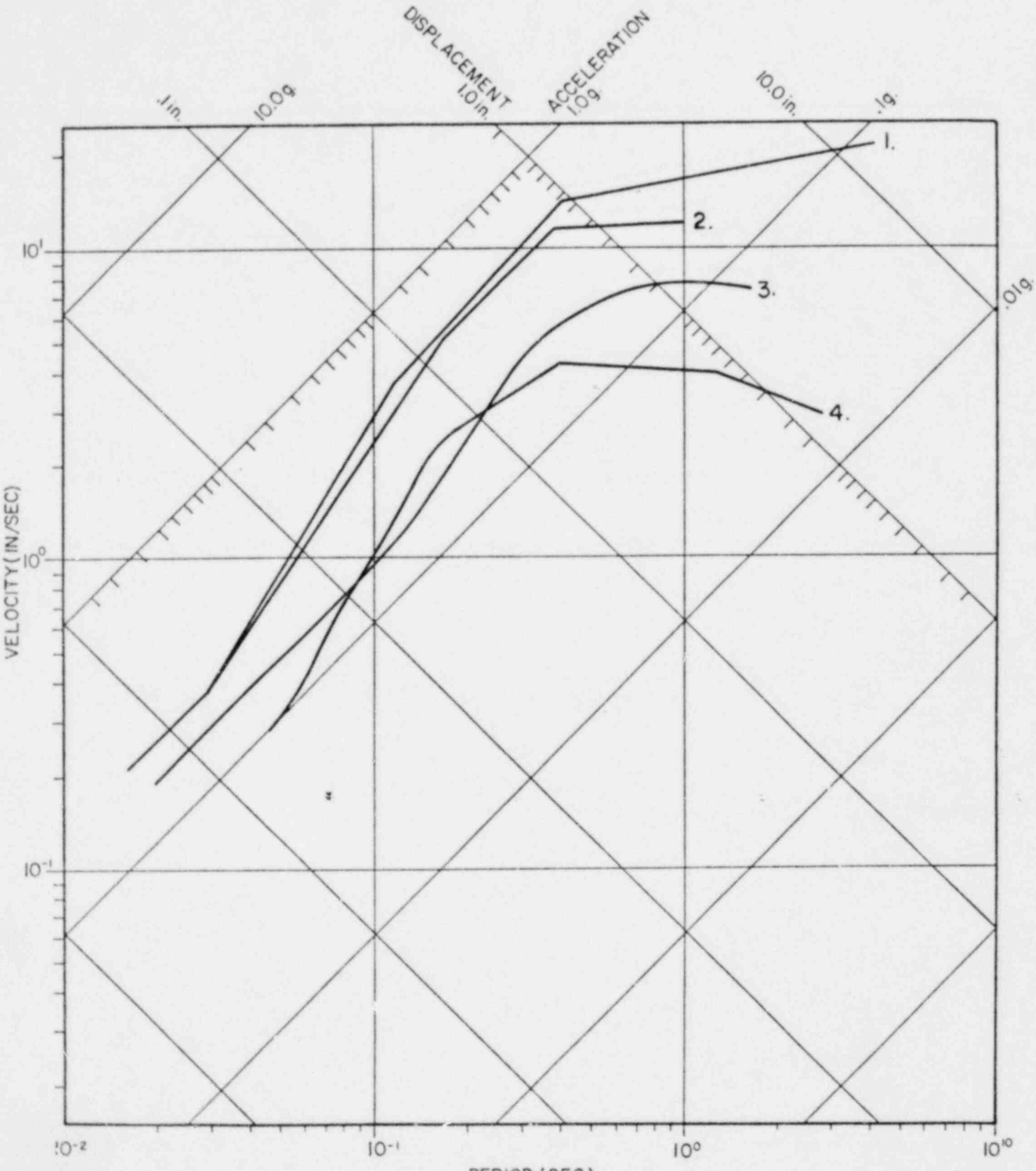
Weston Geophysical



HORIZONTAL SEISMIC DESIGN-RESPONSE SPECTRA
HADDAM NECK NUCLEAR POWER PLANT
(5,7,10, and 20% Critical Damping)

FIGURE 11

Weston Geophysical



1. REG GUIDE, 1.60 .21g (5%)
2. NUREG 0098 .21g (5%) NRC RECOMMENDATION
3. HOUSNER (FSAR) .17g (5%)
4. SITE SPECIFIC SPECTRA (5%) THIS STUDY

COMPARISON OF HORIZONTAL RESPONSE SPECTRA

FIGURE 12

Weston Geophysical

APPENDIX A

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1647	611	13 0	42.800	70.800		IV			202.4
1677	1213	0 0	41.050	73.530		IV			98.4
1685	218	0 0	42.700	70.800		IV			194.6
1705	627	0 0	42.350	71.060		IV			153.0
1727	11 9	2240	42.800	70.600		VII			214.1
1727	11 9	2335	42.800	70.600		IV			214.1
1727	1110	215	42.800	70.600		IV			214.1
1727	1114	17 0	42.800	70.600	-	V			214.1
1727	1118	1120	42.800	70.600		IV			214.1
1727	12 1	0 0	42.800	70.600		IV			214.1
1727	1216	0 0	42.800	70.600		IV			214.1
1727	1219	10 0	42.800	70.600		IV			214.1
1727	1228	2230	42.800	70.600		IV			214.1
1728	1 4	23 0	42.800	70.600	-	V			214.1
1728	2 4	2130	42.800	70.600		IV			214.1
1728	2 8	630	42.800	70.600		IV			214.1
1728	210	1530	42.800	70.600		V			214.1
1728	516	0 0	42.800	70.600		IV			214.1
1728	730	10 0	42.800	70.600		IV			214.1
1728	8 2	315	42.800	70.600		IV			214.1

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1729	330	14 0	42.800	70.600	IV			214.1
1729	8 6	0 0	41.400	73.500	IV			83.7
1729	1125	8 0	42.800	70.600	IV			214.1
1729	12 8	20 0	42.800	70.600	IV			214.1
1730	3 9	145	42.800	70.600	IV			214.1
1730	423	20 0	42.800	70.600	IV			214.1
1731	112	19 0	42.800	70.600	IV			214.1
1731	122	24 0	42.800	70.600	IV			214.1
1731	1012	23 0	42.800	70.600	IV			214.1
1736	1123	2 0	42.800	70.600	IV			214.1
1737	920	1020	42.800	70.600	IV			214.1
1737	1218	0 0	40.800	74.000	VII			146.4
1744	614	1015	42.500	70.900	VI			173.7
1744	614	17 0	42.520	70.920	IV			173.9
1755	1118	412	42.700	70.300	VIII			226.0
1755	1118	529	42.700	70.300	IV			226.0
1755	1122	2027	42.700	70.300	V			226.0
1755	1219	2015	42.700	70.300	IV			226.0
1757	7 8	1430	42.350	71.100	IV			150.5
1761	11 1	20 0	43.100	71.500	IV			197.5

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1766	1217	1840	43.100	70.800		IV			227.4
1783	1129	1050	41.000	74.500		VI			175.2
1790	725	5 0	41.450	72.460	-	IV			4.9
1791	516	8 0	41.500	72.500	-	VII			2.0
1800	1220	0 0	43.700	72.300		IV			246.7
1801	3 1	1530	43.070	70.770		IV			226.4
1805	425	1820	42.500	70.900		IV			173.7
1807	113	23 0	43.000	71.000		IV			208.7
1807	5 6	13 0	43.480	70.470		IV			277.1
1810	11 9	2115	43.000	70.800		V			218.8
1814	1128	1914	43.700	70.300	-	V			304.8
1817	10 5	1145	42.500	71.200	-	VI			155.8
1823	723	655	42.900	70.600	-	V			221.7
1827	823	0 0	41.400	72.700	-	V			19.0
1837	115	7 0	42.500	70.950		IV			170.6
1837	412	0 0	41.700	72.700	-	V			29.3
1840	116	20 0	43.000	75.000	-	VI			265.6
1840	8 9	1530	41.500	72.900		V			33.3
1840	1111	0 0	39.800	75.200		V			294.2
1845	1026	1815	41.200	73.300	-	VI			73.6

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM	Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1845	11 0	0 0	43.600	72.300		IV			235.7
1846	530	1330	42.700	70.300		IV			226.0
1846	825	445	42.500	70.800		V			180.1
1847	8 8	10 0	41.700	70.100	-	VI			200.6
1847	929	0 0	40.500	74.000		V			166.3
1848	9 8	22 0	40.400	74.000		V			173.9
1852	110	1140	41.200	71.400		IV			96.8
1852	1127	2345	43.000	70.900		V			213.7
1854	1024	22 0	42.900	72.300		IV			158.3
1854	1211	030	43.000	70.800	-	V			218.8
1855	116	18 0	44.000	71.000		V			305.1
1855	116	1920	44.000	71.000		IV			305.1
1855	2 6	2330	42.000	74.000		V			136.9
1855	1217	14 0	43.300	73.700		IV			224.5
1856	312	22 0	41.400	72.600		IV			12.3
1858	630	2245	41.300	73.000	-	V			46.3
1862	2 2	20 0	41.500	72.500		IV			2.0
1871	720	0 0	43.200	71.530		IV			206.6
1871	10 9	940	39.700	75.500		VII			321.0
1872	711	525	40.900	73.800		V			126.3

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1872	1118	14 0	43.200	71.600	-	V			204.5
1874	1 6	0 0	43.600	71.200		IV			258.0
1874	125	12 0	42.600	71.350		IV			156.1
1874	1124	0 0	42.700	70.900		IV			188.8
1874	1210	2225	40.900	73.800		VI			126.3
1875	728	410	41.900	73.000		V			62.2
1875	12 1	0 0	42.900	72.300		IV			158.3
1876	921	2330	[illegible].530	71.280	-	V			101.5
1877	910	959	40.300	74.900	-	V			240.3
1878	2 5	1120	40.000	73.800		V			197.5
1878	10 4	230	41.500	74.000		V			124.7
1879	1025	2230	42.980	71.470		IV			186.6
1880	512	745	42.700	71.000	-	V			183.1
1880	720	19 0	42.980	71.470		[illegible]			186.6
1881	10 6	5 3	43.200	71.550		IV			206.0
1882	417	0 0	43.200	71.700		IV			201.7
1882	1219	1724	43.200	71.400		V			211.0
1883	2 4	20 5	43.600	71.200		IV			258.0
1883	227	2330	41.500	71.300		V			99.8
1884	118	7 0	43.200	71.700		IV			201.7

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM	Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1884	531	0 0	40.600	75.500		V			269.5
1884	810	19 7	40.600	74.000		VII			159.2
1884	811	0 0	40.600	74.000	-	V			159.2
1884	1112	0 0	43.200	71.550		IV			206.0
1984	1123	1230	43.20C	71.700		V			201.7
1884	1217	0 0	43.700	71.500		IV			259.4
1886	1 5	1910	42.900	71.500		IV			177.6
1886	117	1714	42.770	71.450		IV			167.1
1886	125	0 0	41.580	73.800		IV			108.5
1887	630	21 0	43.200	71.530		IV			206.6
1889	3 8	0 0	43.450	71.580		IV			231.1
1889	810	0 0	43.430	73.720		IV			238.2
1891	5 1	1910	43.200	71.600		V			204.5
1891	529	19 0	43.100	71.500		IV			197.5
1892	1211	1130	44.300	71.700		IV			319.5
1893	3 9	030	40.600	74.000		V			159.2
1893	314	0 0	42.350	72.660		IV			97.2
1894	410	0 0	41.600	72.500		IV			13.1
1894	1217	0 0	42.470	73.800		IV			153.4
1895	9 1	6 9	40.700	74.800		VI			211.0

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1896	521	228	43.080	75.230	-	IV			285.8
1896	1022	530	44.300	71.770		IV			318.4
1897	7 1	420	43.700	71.600		IV			256.9
1897	9 5	0 0	41.500	72.500		IV			2.0
1898	611	145	42.830	72.560		IV			149.7
1899	516	2015	41.600	72.600		V			15.5
1903	424	1230	42.700	71.000		IV			183.1
1905	830	1040	43.100	70.700		V			232.6
1905	1126	030	41.500	71.300		IV			99.8
1906	5 8	1330	41.500	72.500		IV			2.0
1906	1019	0 0	43.500	70.500		IV			277.4
1907	124	1130	42.800	74.000		IV			191.4
1907	629	0 0	43.500	70.500		IV			277.4
1907	1016	010	42.800	71.000		V			191.4
1908	531	1742	40.600	75.500		VI			269.5
1908	1123	13 0	43.450	71.650		IV			229.3
1910	123	130	43.800	70.400		IV			309.2
1910	821	1845	42.700	71.100		IV			177.7
1910	830	1430	43.400	72.100		IV			215.4
1911	3 2	2130	43.200	71.530		IV			206.6

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM	Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1913	810	515	44.000	74.000		IV			305.1
1913	11 3	1430	41.400	71.400		IV			91.9
1915	221	2 3	42.800	71.100		IV			186.2
1916	1 5	1356	43.700	73.700		V			265.0
1916	2 3	426	43.000	74.000		V			208.7
1916	6 8	2115	41.000	73.800		IV			120.9
1916	11 2	232	43.300	73.700		V			224.5
1916	12 2	9 0	41.500	72.450	-	IV			4.6
1917	216	9 0	41.500	72.450		IV			4.6
1919	811	0 0	41.470	72.450		IV			4.4
1920	523	8 0	43.100	71.500		IV			197.5
1921	119	10 0	43.300	73.700		IV			224.5
1921	126	2340	40.000	75.000		V			266.9
1921	127	0 0	43.300	73.700		IV			224.5
1922	5 7	2240	43.400	71.400		IV			231.2
1925	1 7	13 7	42.600	70.600		V			199.8
1925	3 9	0 0	42.930	71.470		IV			181.7
1925	424	756	41.700	70.800	-	V			143.1
1925	10 9	1355	43.700	71.100		VI			271.5
1925	1029	0 0	41.500	72.450		IV			4.6

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1925	1114	13 4	41.700	72.400	V			25.6
1925	1116	620	41.770	72.700	IV			36.0
1926	1 4	0 0	41.600	71.800	IV			59.6
1926	126	2340	40.000	75.000	V			266.9
1926	318	21 9	42.800	71.800	V			157.2
1926	512	330	40.900	73.900	V			133.6
1927	3 9	4 8	43.300	71.400	- V			221.0
1927	330	0 0	41.670	72.780	IV			31.2
1927	6 1	1223	40.300	74.000	VII			181.8
1927	820	0 0	42.300	71.000	IV			153.6
1928	113	1950	41.200	71.600	IV			81.2
1928	428	22 7	43.200	71.500	IV			207.6
1930	214	615	43.400	71.700	IV			222.7
1930	319	015	43.300	71.600	IV			214.9
1931	420	1954	43.400	73.700	VII	4.7	5.0	234.5
1931	7 1	245	41.600	73.400	IV			75.9
1933	117	530	41.630	70.930	IV			131.4
1933	125	2 0	40.200	74.700	V			233.1
1933	1029	0 0	43.000	74.700	IV			247.1
1934	130	1030	41.800	72.600	IV			36.3

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1934	8 2	1458	42.600	70.700		IV			193.4
1934	8 2	1459	43.700	70.300		IV			304.8
1934	8 3	230	43.700	70.300		IV			304.8
1935	424	124	42.170	70.220		IV			203.4
1936	1110	246	43.550	71.430		V			245.7
1937	719	351	40.720	73.710		IV			131.9
1937	727	910	41.830	72.430		IV			39.1
1938	623	357	42.620	71.420		IV			154.5
1938	8 2	9 2	41.080	73.700	-	IV			109.6
1938	823	336	40.100	74.500		V	3.9	4.6	227.5
1938	823	5 4	40.250	74.250			4.0	4.8	200.7
1938	823	7 3	40.250	74.250			3.7	4.6	200.7
1939	1115	254	39.600	75.200		V			309.0
1940	128	2311	41.630	70.800		V	2.6	4.3	142.1
1940	3 2	415	41.500	72.500		IV			2.0
1940	313	129	41.500	72.500		IV			2.0
1940	1220	727	43.800	71.300		VII	5.4	5.8	275.3
1940	1224	1343	43.800	71.300		VII	5.4	5.8	275.3
1940	1225	5 3	43.800	71.300			3.7	4.0	275.3
1940	1227	1956	43.800	71.300			3.8	3.9	275.3

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1941	121	227	43.800	71.300		2.8	3.6	275.3
1942	1024	1727	40.970	75.250			3.4	236.4
1943	314	14 2	43.700	71.570			3.9	257.7
1944	2 5	1622	40.800	76.200			3.7	318.3
1944	1214	315	41.600	72.800	IV	3.5		28.1
1947	1 4	1851	41.030	73.580	IV			103.1
1948	5 4	223	41.380	71.830	IV			56.9
1949	417	015	41.600	71.500	IV			84.1
1950	320	2255	41.500	75.800			3.3	274.3
1950	329	1443	41.050	73.600	IV			103.5
1951	126	327	41.500	72.500	IV			2.0
1951	331	350	42.200	72.200	IV			83.5
1951	610	1720	41.500	71.500	IV			83.1
1951	9 3	2126	41.250	74.250	V	3.8	4.4	148.0
1951	1123	645	40.600	75.500	IV			269.5
1952	825	0 7	43.000	74.500	V			235.3
1952	10 8	2140	41.700	74.000	V			126.8
1953	327	850	41.100	73.500	V	3.0		93.5
1953	331	1258	43.700	73.000	V		4.0	249.6
1953	511	613	43.980	71.130	IV			298.9

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1953	817	422	41.000	74.000		IV			136.1
1954	1 7	725	40.300	76.000		VI			321.6
1954	331	2125	40.250	74.000		IV			185.9
1954	729	1957	42.700	70.700		V		4.0	200.6
1955	121	840	42.970	73.780		V			195.8
1957	323	19 2	40.630	74.830		VI			216.7
1958	5 6	19 0	42.650	73.820		IV			169.2
1958	719	1745	43.600	70.200		V			301.0
1958	1121	2330	43.970	71.680		IV			284.1
1959	413	2120	41.920	73.270				3.4	80.2
1960	122	2053	41.500	75.500				3.4	249.4
1961	914	2117	40.750	75.500		V		4.3	263.6
1961	1227	17 6	40.500	74.750		V		4.3	217.7
1962	410	1430	44.100	73.400		V		5.0	299.7
1962	1229	619	42.800	71.700		V		4.3	160.4
1963	3 2	2024	41.510	75.730				3.4	268.5
1963	519	1914	43.500	75.230				3.5	316.3
1963	7 1	1959	42.570	73.750				3.3	158.7
1963	1016	1531	42.500	70.800		V	3.9	4.2	180.1
1963	1030	1736	42.700	70.800	-	V	2.4	5.0	194.6

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
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DATE		ORIGIN	EPICENTER		INTENSITY		MAGNITUDE		DISTANCE
Year	MoDa	HrMn	Lat(N)	Long(W)	MM	Scale	mb	ML	To Site(km)
1963	12 4	2132	43.600	71.600	-	V		3.7	246.3
1964	4 1	1121	43.600	71.500		IV	1.8		248.9
1964	626	11 4	43.300	71.900		V	2.6	3.6	207.7
1964	1117	17 8	41.200	73.700		V		4.3	104.8
1965	929	1557	41.400	74.400		IV			158.3
1965	1024	1745	41.300	70.100		V		4.3	200.8
1965	12 8	3 3	41.700	71.400	-	V		4.3	94.4
1966	1023	23 5	43.000	71.800	-	V		3.1	178.0
1967	2 2	1340	41.400	71.400		V		2.4	91.9
1967	515	2247	42.300	69.900				3.2	233.2
1967	1122	2210	41.200	73.800		V			112.7
1968	11 3	833	41.400	72.500		V			9.1
1968	1210	412	39.700	74.600		V		2.5	265.4
1969	8 6	16 3	43.800	71.400		V			272.5
1969	10 6	0 0	41.000	74.600		IV			183.2
1970	919	1335	42.950	71.870		IV			171.0
1971	1021	054	42.700	71.150		V			175.0
1973	228	821	39.720	75.440		V	3.8		315.6
1974	428	1419	39.750	75.550		IV			320.9
1974	6 7	1945	41.570	73.940			3.3		120.0

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM	Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1975	11 3	2054	43.890	74.640			3.9		319.2
1975	11 3	21 6	43.890	74.650			4.0		319.7
1976	311	829	41.560	71.210			3.5		107.5
1976	413	1539	40.800	74.030			3.1		148.6
1976	424	1022	41.460	72.490		IV	2.2		2.6
1976	510	134	41.540	71.010		V	2.7		124.0
1977	1220	1744	41.822	70.758		IV	3.1		149.3
1977	1225	1535	43.200	71.641		IV	3.2		203.3

THIS CATALOG CONTAINS 268 EARTHQUAKES

EARTHQUAKES WITH INTENSITY > III OR MAGNITUDE > 3.0
LOCATED WITHIN 200 MILES (322 KM) OF THE HADDAM NECK SITE

DATE Year	MoDa	ORIGIN HrMn	EPICENTER Lat(N)	Long(W)	INTENSITY MM	Scale	MAGNITUDE mb	ML	DISTANCE To Site(km)
1975	11 3	2054	43.890	74.640			3.9		319.2
1975	11 3	21 6	43.890	74.650			4.0		319.7
1976	311	829	41.560	71.210			3.5		107.5
1976	413	1539	40.800	74.030			3.1		148.6
1976	424	1022	41.460	72.490		IV	2.2		2.6
1976	510	134	41.540	71.010		V	2.7		124.0
1977	1220	1744	41.822	70.758		IV	3.1		149.3
1977	1225	1535	43.200	71.641		IV	3.2		203.3

THIS CATALOG CONTAINS 268 EARTHQUAKES