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ANALYSIS OF STRONG-MOTION DATA FROM THE NEW HAMPSHIRE EARTHQUAKE OF 18 JANUARY 1982

by

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Final Report

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acceleration, peak velocity, peak displacement, and velocity spectrum intensity on the crest, abutment, and downstream sites of the five US Army Corps of Engineers earth dams were plotted and compared. The transverse component at the Franklin Falls Dam shows the highest energy. However, its attenuation rate is faster than the vertical and longitudinal components. The transverse component of the accelerograph located on the right abutment of Franklin Falls Dam (8 km from the epicenter) recorded a maximum acceleration of 0.55 g's, which is the highest acceleration ever recorded in the eastern United States. The integrated maximum velocity is 5.59 cm/sec, which is very low in comparison with other earthquake records in the western United States.

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PREFACE

This report was prepared during the period April to August 1982 by Mr. Frank K. Chang, Research Geophysicist of the Earthquake Engineering and Geophysics Division (EE&GD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), under Contract No. RES-79-115MOD2, U. S. Nuclear Regulatory Commission (NRC). The work was monitored by Dr. Andrew J. Murphy, Seismologist, Earth Sciences Branch, NRC.

Mr. Lewis B. Smithhart, Electronics Technician of the Instrumentation Services Division (ISD), WES, and Mr. Frank Risavich, Electronics Technician of the U. S. Geological Survey (USGS), collected the strong-motion records and calibrated the accelerographs under conditions of cold weather and heavy snow cover. Mr. Monroe B. Savage, Electronics Engineer, ISD, maintained the strong-motion instruments and provided the instrument calibration data for this report. IOM-Towill (I/O Metrics Corporation and R. M. Towill Corporation), an automated laser line digitizing service, digitized the accelerograms. Dr. A. G. Brady and Mr. Peter Moak, USGS, provided the data correction and integration. Mr. Howard Gary, Senior Scientific Programmer, Computer Data Systems, Inc., assisted with data processing.

Preparation of the report was under the direction of Mr. R. F. Ballard, Jr., EE&GD. General direction was by Dr. A. G. Franklin, Chief, EE&GD, and Dr. W. F. Marcuson III, Chief, GL.

COL Tilford C. Creel, CE, was Commander and Director of WES during the period of this study. Mr. Fred R. Brown was Technical Director.

ABSTRACT

This report provides a permanent record and presents an analysis of the strong-motion data from the New Hampshire earthquake of 18 January 1982 which occurred at latitude 43.5 degrees N, longitude 71.6 degrees W. Thirty-six accelerograms were recorded and digitized. The raw digitized accelerograms were processed by the U. S. Geological Survey, Seismic Engineering Branch, to provide baseline correction and integrals are presented in tabular and graphic form. The integrated velocities and displacements are presented in graphic form.

The attenuation curves of the three orthogonal components for peak acceleration, peak velocity, peak displacement, and velocity spectrum intensity on the crest, abutment, and downstream sites of the five U. S. Army Corps of Engineers earth dams were plotted and compared. The transverse component shows the highest energy at the Franklin Falls Dam. However, its attenuation rate is faster than the vertical and longitudinal components.

The transverse component of the accelerograph located on the right abutment of Franklin Falls Dam (8 km from the epicenter) recorded a maximum acceleration of 0.55 g's, which is the highest acceleration ever recorded in the eastern United States. The integrated maximum velocity is 5.59 cm/sec, which is very low in comparison with other earthquake records in the western United States or other earthquake regions.

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TABLE 7. Instrument Characteristics for the New Hampshire Earthquake

TABLE 8. Instrument Characteristics for the New Hampshire Earthquake

A NOTE: These numerical acceleration values can be obtained in computer format from the World Data Center A for Solid Earth Geophysics and the National Geophysical and Polar-Terrestrial Data Center (NGPCD). The address is listed as follows: NGPCD, National Geophysical Data Center (3023), Boulder, Colorado 80303; Telephone 303 (303) 497-4141 or 303 440-6100.

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* NOTE: These material acceleration values can be obtained in tape format from the World Data Center A for Solid Earth Geophysics and the National Geophysical and Solar-Terrestrial Data Center (NGSDC). The address is listed as follows: EDIS/NOAA, National Geophysical Data Center (D622); Boulder, Colorado 80303; Telephone No. (303) 497-6764, or FTS 320-6764

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* NOTE: These material acceleration values can be obtained in tape format from the World Data Center A for Solid Earth Geophysics and the National Geophysical and Solar-Terrestrial Data Center (NGSDC). The address is listed as follows: NGSDC, National Geophysical Data Center (2612); Boulder, Colorado 80502; Telephone No. (303) 447-6144, or FTS 350-6144.

INTRODUCTION

An earthquake occurred at 19:14:42 EST on 18 January 1982 (UT 00:14:42, 19 January 1982) north of Tilton (near Franklin), New Hampshire. The geographic coordinates of the epicenter are 42.5 degrees N and 71.6 degrees W. Slight damage, Modified Mercalli (MM) Intensity VI, was observed at Bristol, Canaan, and Danbury, New Hampshire, and North Hartland and White River Junction, Vermont. The shock was felt throughout most of New England, northern New York, and as far away as southern Quebec and northeastern Ontario. The Richter magnitude was determined by the U. S. Geological Survey (USGS) (USGS, 1982) to be 4.7 ($m_b = 4.4$, $m_{bLg} = 4.5$). The focal depth was between 4.5 and 8.0 km (personal communication, John E. Ebel, Weston Observatory).

The U. S. Army Corps of Engineers Division, New England (NED), had strong-motion accelerographs at 12 dams in New England. Eleven three-component accelerographs at five of the dams, plus one instrument at a Veterans Administration (VA) hospital, recorded this earthquake. All of these instruments are maintained by the U. S. Army Engineer Waterways Experiment Station (WES) under the U. S. Army Corps of Engineers (CE) Strong-Motion Instrumentation Program. This is the first time 36 accelerographs were recorded in a single earthquake in the eastern United States. Figure 1 shows the locations of the six recording stations and distances from the epicenter. Table 1 provides further information on the recording sites.

Thirty-six accelerographs were recovered and developed by WES. Photocopies of the raw data are presented in Appendix A. The uncorrected peak accelerations recorded at the abutment, crest, and downstream sites are listed in Table 2. At Ball Mountain usable records were observed only from the crest and not from instruments at the abutment and downstream sites. The records at the abutment and downstream sites show very small amplitudes from which meaningful digital values could not be obtained.

Franklin Falls Dam is an earth dam at a distance of about 8 km from the epicenter. Only minor damage to the gatehouse at this dam has been reported. At this location nine channels of acceleration data were recorded. The predominant frequency recorded at Franklin Falls (11 to 21 Hz) is higher than those typical of the West Coast (4 to 6 Hz). The frequency range of 11 to 21 Hz can be significant to the response of many nuclear power plant systems and structures.

PURPOSE

The purpose of this report is to present the original earthquake records, the corrected digitization of the 36 accelerographs, the integrated velocities, and the displacements. The uncorrected digital accelerographs are filed on magnetic tapes which can be ordered from the National Geophysical and Solar-Terrestrial Data Center, Code 62, EDS/NOAA,

Boulder, CO 80302. a collection of 108 response spectra of accelerations, velocities, and displacements will be published in a WES report.

INSTRUMENT CHARACTERISTICS

The instrument characteristics of the accelerographs are listed in Table 3.

DATA DIGITIZATION AND PROCESSING

Digitization

The 36 accelerograms were digitized with a laser line digital machine by IOM-Towill (I/O Metrics and R. M. Towill Corporation) of Santa Clara, California. The accelerograms were measured to a center-line accuracy of better than 3 micrometers (0.0001 in.) with a spacing between points of 20 micrometers (0.0007 in.). The 3 accelerograms recorded at the right abutment of the Franklin Falls Dam were digitized at 600 points per second, the remainder at 200 points per second. The 36 uncorrected accelerograms were stored on a magnetic tape which is kept in the Seismic Engineering Branch (SEB), USGS, Menlo Park, California, with the original 35-mm records.

Baseline Correction

The basic concept of baseline correction is to subtract from the raw accelerogram a low-pass filtered version of the accelerogram, using Ormsby's filter (Ormsby, 1961) in which all frequencies higher than 0.07 Hz have been removed. The result is a high-pass filtered accelerogram from which low frequency noise is eliminated. This is part of the standard routine processing of accelerograms (Hudson and others, 1971; and Trifunac and Lee, 1973). The general procedure of baseline correction for this report is the same as mentioned above except that Ormsby's filter had been replaced by an equivalent Butterworth filter (USGS, 1976) and some minor changes. Details of these and other data-processing procedures are discussed in a User's Manual for the computer code AGRAM by Converse (USGS, 1983).

Data Processing

The 36 corrected accelerograms, velocities, displacements, and their response spectra were processed by the SEB using their standard routine computer program AGRAM and were stored on another magnetic tape. Plots showing the corrected acceleration, velocity, and displacement curves, and the numerical presentation in this volume were prepared by WES.

The spectra of absolute response acceleration, relative response velocity, and relative response displacement will be published in a separate Nuclear Regulatory Commission (NRC) report.

DATA PRESENTATION

Station, site location, coordinates, epicentral distances, azimuth from source to accelerograph site, instrument component, uncorrected maximum acceleration, corrected maximum acceleration, maximum particle velocity, maximum displacement, velocity spectrum intensity, and ratio of $a \cdot d/v^2$, v/a , and a_v/a_h are listed in Table 2. By definition, the spectrum intensity is the area under the velocity spectrum curve, of 5 percent critical damping, between 0 and 4.0 sec period.

$$SI_{\zeta} = \int_0^{4.0} S_v(\zeta, T) dT$$

where ζ is the amount of damping. In this report, $\zeta = 5$ percent. The area under a curve is a measure of the intensity of the ground motion for the range of periods and that amount of damping.

DATA ANALYSIS

The 27 records from Union Village Dam, North Hartland Dam, White River Junction VA Hospital, North Springfield Dam, and Ball Mountain Dam were all obtained at sites located in Vermont, to the west of the epicenter, at distances between 60 and 103 km as shown in Figure 1. The VA Hospital accelerograph at Manchester, New Hampshire, about 57.5 km south of the epicenter, was not triggered by the earthquake. The strong-motion stations, at CE dams located near Townsend, Vermont, and Surry, New Hampshire, about 99 km and 78 km, respectively, from the epicenter also did not record any values. No strong-motion instruments in Massachusetts were triggered by the earthquake. The ground motion was evidently strongest westward from the source. The direction of the horizontal resultant peak ground acceleration at Franklin Falls Dam was in the range between N64 degrees W to N74 degrees W as shown in Figure 2, which was determined from the two horizontal maximum accelerations at the downstream, crest, and abutment sites, i.e.,

$$(a_L)_{\max} \leftrightarrow (a_T)_{\max}$$

where

$\oplus$ = addition of two vectors L and T

$(a_L)_{\max}$ = maximum acceleration of longitudinal component

$(a_T)_{\max}$ = maximum acceleration of transverse component

The best way to determine the direction of the ground motion is to use the first motion of the records. However, this was not done in this case due to the trigger level of the strong-motion instrument.

The corrected maximum acceleration of 0.55 g's recorded on the transverse component of the accelerograph at the right abutment (rock) of Franklin Falls Dam is the highest acceleration ever recorded in the eastern United States. However, the corresponding integrated maximum velocity is 5.59 cm/sec. In comparing this value with the Melendy Ranch records of the 4 September 1972 Stone Canyon, California, earthquake ($M = 4.7$) with maximum acceleration of 506.12 cm/sec² and a velocity of 13.72 cm/sec on the N29 degrees W component, the particle velocity for Franklin Falls Dam is much less than the Melendy Ranch record. This difference is probably caused by the predominant frequency content, 11 Hz for the former and 5 Hz for the latter.

It is noted from Table 2 that the maximum acceleration recorded on the crest of the Franklin Falls Dam did not amplify due to the height of the 45-m earth dam. Actually, the peak ground acceleration recorded at the downstream site was even somewhat higher than that on the crest.

Because of the lack of the strong-motion data in the eastern United States, the attenuation of ground motion is always a problem. For the first time, 36 accelerograms have been recorded for one earthquake in the eastern United States. Even though the data are not sufficient or not evenly distributed with distance and it would be better to make an analysis for the attenuation of ground motion using data for different site conditions, the analysis was performed because these are the first data from this region. The 36 records were recorded on the crest, abutment, and downstream sites of five earth dams and at one basement of the VA Hospital, i.e., Franklin Falls Dam (FFD), Union Village Dam (UVD), North Hartland Dam (NHD), North Springfield Dam (NSD), Ball Mountain Dam (BMD), and VA Hospital at White River Junction (WRJ). The location distribution of the 36 records is shown in Table 1.

All five earth dams are located in different valleys and their geometrical boundaries are certainly critical to the ground motion. Generally, the two horizontal components of an accelerograph on the crest of a dam are oriented parallel to the dam axis (longitudinal component) and perpendicular to the dam axis (transverse component). For the purpose of comparison, the accelerographs located on the abutment and downstream are oriented the same as on the crest. Thus, in terms of site topography the longitudinal component is approximately the motion perpendicular to the valley axis and the transverse component the motion parallel to the valley axis. Figure 1 shows the direction of

the longitudinal axis of each earth dam and the orientation is also given in Tables 2 and 3. If desired, the transverse and longitudinal components can be resolved into the radial and tangential components with respect to the ray path from the focus.

Figures 3a, b, c, and d show the attenuation curves of the three orthogonal components for peak ground accelerations (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and velocity spectrum intensity (VSI) on the crest, abutment, and downstream sites for the five CE earth dams.

The general attenuation characteristics of the ground motion are shown as follows. The attenuation rate of PGA, PGV, and VSI on the crest site is about the same as on the downstream site. Attenuation is naturally faster on the abutment (rock) than on the crest and downstream sites. The energy or amplitude of the transverse components at the Franklin Falls Dam is higher than other two components. However, the rate of attenuation for the transverse component is faster than for the longitudinal and vertical components. The attenuation trend of PGV and VSI is similar, because both are based on the same concept of energy. The PGD for the downstream site is somewhat lower than the crest site and overall the presentation is not as unique as PGA, PGV, and VSI curves due to the double integration of the long-period waves.

Based on the statistical analysis of the peak ground motions, a , v , and d , it has been found that the average ratio of v/a for the 36 components of this earthquake is 0.0204 sec. The average ratio of v/a for the 110 components of the western United States is about 5 times higher than for this New Hampshire earthquake. The average ratio of a_v/a_h (vertical maximum acceleration to horizontal maximum acceleration) for this earthquake is 0.83. Uwabe* and others (1977) found the average ratios of a_v/a_h for Japan and the western United States are 0.33 and 0.48, respectively. The cause of this difference needs further investigation.

The average ratio of ad/v^2 for 189 vertical components of the strong-motion earthquake records in the western United States is 6.62 ± 4.30 and for 382 horizontal components 5.30 ± 3.84 . The former is about 25 percent higher than the latter. However, in the eastern United States, the average ratio of ad/v^2 for the 12 vertical components of this New Hampshire earthquake is 10.116 ± 4.387 and for the 24 horizontal components is 7.903 ± 3.678 . The former is about 28 percent higher than the latter. For most earthquakes of practical interest, Newmark and Rosenbluth (1971) give $ad/v^2 = 5$ to 15. This is in agreement with the present study.

* Uwabe, T. 1979. "Comparison of Vertical Components of Strong-Motion Accelerograms for Western United States and Japan," unpublished report, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

SUMMARY

Thirty-six analog accelerograms of the New Hampshire earthquake of 18 January 1982, which occurred at latitude 43.5 degrees N, longitude 71.6 degrees W, were digitized, corrected, and integrated. The corrected accelerograms were presented in tabular and graphic form. The integrated velocities and displacements are presented in graphic form.

Results of the 36 accelerograph records such as uncorrected maximum accelerations, corrected maximum acceleration (a), velocity (v), and displacement (d), velocity spectrum intensity, and the ratio of ad/v , v/a , $(v/a)_{\text{vert}}/(v/a)_{\text{hori}}$, and $a_{\text{vert}}/a_{\text{hori}}$ are listed in Table 2.

Eleven accelerographs on the five earth dams of the CE and one accelerograph in the basement of White River Junction VA Hospital in Vermont recorded the earthquake. The five earth dams are Franklin Falls, New Hampshire; Union Village, Vermont; North Hartland, Vermont; North Springfield, Vermont; and Ball Mountain, Vermont. No strong-motion instruments in Massachusetts were triggered by the earthquake. The direction of the horizontal resultant force was within the range of N64 degrees W and N74 degrees W.

The maximum acceleration of 0.55 g's recorded on the transverse component at the right abutment (rock) of Franklin Falls Dam is the highest acceleration ever registered in the eastern United States. However, the corresponding integrated maximum velocity is 5.59 cm/sec, which is much lower than is typical at the same acceleration level and earthquake magnitude for the western United States.

It is noted that the maximum acceleration on the crest of the Franklin Falls Dam was not amplified by the height of the 45-m earth dam.

The attenuation curves of the three orthogonal components for PGA, PGV, and VSI on the crest, abutment, and downstream sites of the five CE dams were plotted and compared. The transverse components show highest energy in almost every site except for the downstream site of the Union Village Dam, but the rate of attenuation is faster than the rates of the other two components. Attenuation rate for the crest and downstream sites is similar and is slower than on the abutment (rock) sites.

The average ratio of v/a for the western United States is about 5 times higher than this for the New Hampshire earthquake. The average ratio of a_v/a_h for this earthquake is 0.83, which is higher than the 0.48 for the western United States and 0.33 for Japan. The ratio of ad/v^2 for the vertical component is higher than for the horizontal component.

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Table 1

Sites of Strong-Motion Records

<u>Owner</u>	<u>Recording Site</u>	<u>Epicentral Distance km</u>	<u>Height of Dam, m</u>	<u>Top Elevation of Crest msl, m</u>	<u>Location of Recording Instrument</u>	<u>Number of Records</u>	<u>Type of Structure</u>
NED	Franklin Falls Dam (FFD)	8	45	130	Crest, right abutment, down- stream toe	9	Earth dam
NED	North Springfield Dam (NSD)	76	38	178	Crest, down- stream	6	Earth dam
NED	Ball Mountain Dam (BMD)	103	81	329	Crest	3	Earth dam
NED	Union Village Dam (UVD)	60	53	183	Crest, left abut- ment, downstream	9	Earth dam
NED	North Hartland Dam (NHD)	61	58	179	Crest, left abut- ment	6	Earth dam
VA	White River Junction (WRJ)	60	--	--	Basement	3	Three-story building
TOTAL						36	

Table 2
Results of CE Accelerograph Records Obtained from
New Hampshire Earthquake of 18 January 1982

Station	Site Location	Azimuth of Component	Azimuth* deg	Uncorrected Accelerations cm/sec ²	Corrected			Velocity Spectrum Intensity 5%, ξ	$\frac{a \cdot d}{v^2}$		$\frac{v}{a}$		(v/a) vert. (v/a) hori.	$\frac{a_{vert}}{a_{hori}}$	
					Maximum Acceleration (a), cm/sec ²	Maximum Velocity (v) cm/sec	Maximum Displacement (d) cm		Hori.	Vert.	Hori.	Vert.			
Franklin Falls Dam Epicenter Distance = 8 km	Downstream	L-225°	234.5	111.68 (21 Hz)	140.70 (0.143 g)	2.03	0.16	9.53	5.464		0.0144		0.443	1.926	
		Up		208.34 (21 Hz)	271.00 (0.276 g)	1.73	0.08	7.29		7.251		0.0064			
		T-135°		267.94 (16 Hz)	377.86 (0.385 g)	2.87	0.17	13.23	7.798		0.0076		0.842	0.717	
	Right Abutment	L-45°		282.52 (14 Hz)	287.70 (0.293 g)	2.68	0.25	13.08	10.017		0.0093		1.150	0.601	
		Up		171.89 (20 Hz)	172.89 (0.176 g)	1.86	0.41	11.61		20.487		0.0107			
		T-315°		565.05 (14 Hz)	539.96 (0.550 g)	5.59	0.43	22.39	7.432		0.0103		1.039	0.320	
	Crest	L-45°		102.79 (11.4 Hz)	123.96 (0.126 g)	2.67	0.36	12.09	6.259		0.0215		1.176	0.922	
		Up		111.38 (11.4 Hz)	114.31 (0.116 g)	2.89	0.47	13.15		6.432		0.0253			
		T-315°		243.46 (14 Hz)	306.83 (0.312 g)	4.06	0.33	17.12	6.143		0.0132		1.916	0.372	
Union Village Dam Epicenter Distance = 60 km	Crest	L-245°	300.0	24.08	22.46	0.46	0.04	2.32	4.246		0.0205		0.883	1.031	
		Up		23.31	23.17	0.42	0.04	2.19		5.254		0.0181			
		T-155°		25.73	25.07	0.50	0.005	2.67	0.501		0.0199		0.909	0.924	
	Left Abutment	L-245°		9.05	9.49	0.15	0.03	0.95	12.653		0.0158		1.727	0.654	
		Up		6.00	6.21	0.17	0.05	1.04		10.744		0.0273			
		T-155°		7.17	6.73	0.23	0.06	1.39	7.633		0.0341		0.801	0.922	
	Downstream	L-245°		38.15	37.01	0.82	0.08	3.54	4.403		0.0221		0.706	0.781	
		Up		27.02	28.90	0.45	0.07	2.37		9.990		0.0156			
		T-155°		22.96	22.58	0.47	0.05	2.45	5.111		0.0208		0.750	1.279	
North Hartland Dam Epicenter Distance = 61 km	Left Abutment	L-15°	178.5	6.66	11.08	0.20	0.05	1.24	13.850		0.0180		2.072	0.338	
		Up		3.56	3.75	0.14	0.04	0.95		7.653		0.0373			
		T-285°		6.35	6.84	0.22	0.06	1.45	8.479		0.0321		1.162	0.548	
	Crest	L-15°		33.57	37.34	0.76	0.12	3.74	7.757		0.0203		1.354	0.448	
		Up		17.12	16.73	0.46	0.09	2.40		7.116		0.0275			
		T-285°		29.39	38.19	0.86	0.13	3.86	6.712		0.0225		1.222	0.438	
	North Springfield Dam, Epicenter Distance = 76 km	Crest	L-275°	255.5	26.05	24.38	0.56	0.06	2.38	4.664		0.0229		0.659	0.921
			Up		22.61	22.45	0.34	0.06	1.91		11.652		0.0151		
			T-185°		21.55	21.54	0.41	0.09	2.59	11.532		0.0190		0.795	1.042
Downstream		L-275°		24.88	31.08	0.41	0.07	1.74	12.942		0.0132		1.159	0.439	
		Up		14.20	13.66	0.21	0.05	1.39		15.487		0.0153			
		T-185°		20.72	22.59	0.29	0.06	1.76	16.116		0.0128		1.195	0.605	
Ball Mountain Dam Epicenter Distance = 103 km	Crest	L-30°	245.6	8.75	8.80	0.37	0.08	2.15	5.142		0.0420		0.676	1.360	
		Up		11.97	11.97	0.34	0.07	1.92		7.248		0.0284			
		T-300°		10.38	10.03	0.37	0.07	2.27	5.128		0.0369		0.769	1.193	
White River Junction (VA Hospital) Epicenter Distance =	Basement	L-270°	285.0	14.80	15.00	0.33	0.06	2.04	8.264		0.0220		0.791	1.454	
		Up		21.34	21.81	0.38	0.08	2.40		12.083		0.0174			
		T-180°		29.04	31.00	0.57	0.12	3.23	11.449		0.0184		0.946	0.703	
Data No.:									24	12	24	12	24	24	
Mean:									7.903	10.116	0.0204	0.0203	1.047	0.830	
SD:									3.678	4.387	0.0086	0.0088	0.400	0.403	
Mean & SD:									11.581	14.403	0.0290	0.0291	1.447	1.233	

* Azimuth is from epicenter to the recording site. Azimuth is also related to geographical north.

Table 3

Instrument Characteristics for the New Hampshire Earthquake, 1/18/1982, 19:14:42 EST

Code	Coordinates	Type and Serial No.	Station Location	Component* Direction	Period T_o , (sec)	Sens.* (cm/g)	Damp.* % Crit.	Starter Sensitivity (g)
FFD	43.447N 71.660W	SMA-1 4576	2627 Downstream Franklin Falls Dam (CE), N. H.	L-225	0.040	1.91	60.0	0.01
				V-Up	0.039	1.80	60.0	
				T-135	0.039	1.85	60.0	
FFD		TT350 1001	2627 Rt. Abutment Franklin Falls Dam (CE), N. H.	L-45	0.050	1.80	59.1	0.01
				V-Up	0.050	1.80	59.1	
				T-315	0.050	1.80	59.1	
FFD		TT350 1018	2627, Crest Franklin Falls Dam (CE), N. H.	L-45	0.051	1.77	62.0	0.01
				V-Up	0.049	1.75	62.0	
				T-315	0.050	1.65	61.0	
UVD	43.794N 72.258W	SMA-1 3390	2632, Crest Union Village Dam (CE), Vt.	L-245	0.039	1.81	60.0	+0.0106
				V-Up	0.037	1.75	60.0	-0.0101
				T-155	0.039	1.91	60.0	

(Continued)

* Static Magnification, $V_s = \omega_n^2 \cdot (\text{Sensitivity}) = \left[\frac{2\pi}{T_o(\text{sec})} \right]^2 \cdot \frac{\text{Sensitivity (cm/g)}}{980 (\text{cm/sec}^2/\text{g})}$

Periods, sensitivities, and damping values are obtained from the regularly updated listing of Strong-Motion Station Instrumental Data,

Damping ratio, $\epsilon = \exp \{ \pi n / \sqrt{1-n^2} \}$, where n is the fraction of critical damping.

The component direction is that of pendulum motion for the trace to be deflected "upwards" on the record, as described in the Notes.

Table 3 (Concluded)

Code	Coordinates	Type and Serial No.	Station Location	Component* Direction	Period T_o , (sec)	Sens.* (cm/g)	Damp.* % Crit.	Starter Sensitivity (g)
UVD		SMA-1	2632, Lt. Abutment	L-245	0.037	1.635	62.0	+0.011
		3391	Union Village Dam	V-Up	0.038	1.75	57.0	-0.010
			(CE), Vt.	T-155	0.038	1.82	61.0	
UVD		SMA-1	2632, Downstream	L-245	0.037	1.75	60.0	<+0.01
		3389	Union Village Dam	V-Up	0.039	1.74	60.0	
			(CE), Vt.	T-155	0.039	1.89	60.0	
NHD	43.604N 72.361W	SMA-1	2629, Abutment	L-15	0.038	1.84	62.0	+0.0095
		3366	North Hartland Dam	V-Up	0.038	1.815	62.5	-0.0100
			(CE), Vt.	T-285	0.038	1.745	62.0	
NHD		SMA-1	2629, Crest	L-15	0.036	1.72	62.0	+0.010
		3366	North Hartland Dam	V-Up	0.038	1.75	62.0	
			(CE), Vt.	T-285	0.038	1.78	55.0	
WRJ	43.63N 72.33W	SMA-1	2604, VA Basement	L-270	0.038	1.94	57.0	+0.008
		0834	White River Junction	V-Up	0.038	1.77	61.0	-0.006
			Vt.	T-180	0.039	1.84	62.0	
BMD	43.12N 72.78W	SMA-1	2617, Crest	L-30	0.0393	1.80	61.0	+0.005
		1230	Ball Mountain Dam	V-Up	0.0406	1.93	59.0	-0.006
			(CE), Vt.	T-300	0.0389	1.90	61.0	
NSD	43.338N 72.511W	SMA-1	2630, Crest	L-275	0.038	1.79	60.0	+0.010
		3373	North Springfield Dam	V-Up	0.038	1.76	60.0	-0.030
			(CE), Vt.	T-185	0.037	1.70	60.0	
NSD		SMA-1	2630, Downstream	L-275	0.039	1.91	60.0	+0.0085
		3371	North Springfield Dam	V-Up	0.038	1.85	60.0	-0.0090
			(CE), Vt.	T-185	0.038	1.87	60.0

Figure 1. Location of epicenter and recording stations

$N64^{\circ}W < \text{HOR. RESULTANTS} < N74^{\circ}W$

Figure 2. Resultant force direction of horizontal peak ground acceleration of crest, downstream, and abutment at Franklin Falls Dam and the direction from dam to epicenter

Figure 3a. Attenuation of peak ground acceleration versus distance at abutment, crest, and downstream of the earth dams

Figure 3b. Attenuation of peak ground velocity versus distance at abutment, crest, and downstream of the earth dams

Figure 3c. Attenuation of velocity spectral intensity versus distance at abutment, crest, and downstream of the earth dams

Figure 3d. Attenuation of peak ground displacement versus distance at abutment, crest, and downstream of the earth dams

APPENDIX A: RECORDED ACCELEROGRAMS

A-2

A-4

1 SEC
1 CM =

ABUTMENT UNION VILLAGE DAM VT

L

V

T

1 CM =
1 SEC

1 SEC
1 CM

DOWNSTREAM UNION VILLAGE DAM VT

L

V

T

1 CM =
1 SEC

1 SEC
1 CM

CREST NORTH SPRINGFIELD DAM VT

L

V

T

1 CM =
1 SEC

A-11

A-13

MAX ACCE = 140.70 CM/S/S , MAX VEL = 2.03 CMS/SEC , MAX DISP = 0.18 CM

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
FRANKLIN FALLS DOWNSTREAM
L-COMPONENT 225 DEG

MAX ACCE = 271.00 CM/S/S , MAX VEL = 1.73 CM/S/SEC , MAX DISP = 0.08 CM

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
FRANKLIN FALLS DOWNSTREAM
V-COMPONENT UP

MAX ACCE = 377.88 CM/SEC/SEC , MAX VEL = 2.87 CM/SEC , MAX DISP = 0.17 CM

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
FRANKLIN FALLS DOWNSTREAM
T-COMPONENT 135 DEG

MAX ACCE = 287.70 CM/SEC/SEC , MAX VEL = 2.88 CM/SEC , MAX DISP = 0.25 CM

MAX ACCE = 172.89 CM/SEC/SEC , MAX VEL = 1.86 CM/SEC , MAX DISP = 0.41 CM

MAX ACCE * 539.96 CM/S/S . MAX VEL * 5.59 CMS/SEC . MAX DISP = 0.43 CM

ACCELERATION, CM/SEC/SEC

VELOCITY, CM/SEC

DISPLACEMENT, CM

MAX ACCE = 6.73 CM/S/S , MAX VEL = 0.23 CM/SEC , MAX DISP = 0.06 CM

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
UNION VILLAGE DAM ABUTMENT
T-COMPONENT 155 DEG

MAX ACCE = 22.68 CM/S/S , MAX VEL = 0.47 CM/SEC , MAX DISP = 0.06 CM

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
UNION VILLAGE DAM DOWNSTRE
T-COMPONENT 155 DEG

MAX ACCE = 11.08 CM/S/S , MAX VEL = 0.19 CMS/SEC , MAX DISP = 0.05 CMS

NEW HAMPSHIRE EQUE
1/18/82.19.14.42 EST
NORTH HARTLAND ABUTMENT
L-COMPONENT 15 DEG

MAX ACCE = 3.75 CM/S/S , MAX VEL = 0.14 CM/SEC , MAX DISP = 0.04 CM

NEW HAMPSHIRE EQUE
1/18/82.19.14.42 EST
NORTH HARTLAND ABUTMENT
V-COMPONENT UP

MAX ACCE = 6.84 CM/S/S . MAX VEL = 0.22 CM/SEC . MAX DISP = 0.07 CM

NEW HAMPSHIRE EQKE
1/18/87 19:14.42 EST
NORTH HARTLAND ABUTMENT
T-COMPONENT 285 DEG

MAX ACCE = 37.34 CM/S/S , MAX VEL = 0.76 CMS/SEC , MAX DISP = 0.12 CMS

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
NORTH HARTLAND CREST
L-COMPONENT 15 DEG

ACCELERATION, CM/SEC/SEC

VELOCITY, CM/SEC

DISPLACEMENT, CM

0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
TIME, SECONDS

MAX ACCE = 16.73 CM/S/S , MAX VEL = 0.46 CMS/SEC , MAX DISP = 0.09 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
NORTH HARTLAND CREST
V-COMPONENT UP

MAX ACCE = 38.19 CM/S/S , MAX VEL = 0.88 CMS/SEC , MAX DISP = 0.13 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
NORTH HARTLAND CREST
T-COMPONENT 285 DEG

MAX ACCE = 24.38 CM/S/S , MAX VEL = 0.56 CMS/SEC , MAX DISP = 0.06 CMS

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
NORTH SPRINGFIELD CREST
L-COMPONENT 275 DEG

MAY ACCE = 22.45 CM/S/S . MAY VEL = 0.34 CM/SEC . MAX DISP = 0.06 CM

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
NORTH SPRINGFIELD CREST
V-COMPONENT UP

MAX ACCE = 21.54 CM/S/S , MAX VEL = 0.41 CMS/SEC , MAX DISP = 0.09 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
NORTH SPRINGFIELD CREST
T-COMPONENT 185 DEG

ACCELERATION, CM/SEC/SEC

VELOCITY, CM/SEC

DISPLACEMENT, CM

MAX ACCE = 31.08 CM/S/S . MAX VEL = 0.41 CMS/SEC . MAX DISP = 0.07 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
N. SPRINGFIELD DOWNSTREAM
L-COMPONENT 275 DEG

MAX ACCE = 13.68 CM/S/S . MAX VEL = 0.21 CMS/SEC . MAX DISP = 0.05 CMS

NEW HAMPSHIRE EQKE

1/18/82.19.14.42 EST

N. SPRINGFIELD DOWNSTREAM

V-COMPONENT UP

MAX ACCE = 22.59 CM/S/S , MAX VEL = 0.29 CMS/SEC , MAX DISP = 0.08 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
N. SPRINGFIELD DOWNSTREAM
T-COMPONENT 185 DEG

MAX ACCE = 8.80 CM/S/S , MAX VEL = 0.37 CMS/SEC , MAX DISP = 0.08 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
BALL MOUNTAIN DAM CREST
L-COMPONENT 30 DEG

MAX ACCE = 11.97 CM/S/S . MAX VEL = 0.34 CMS/SEC . MAX DISP = 0.07 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
BALL MOUNTAIN DAM CREST
V-COMPONENT UP

MAX ACCE = 10.03 CM/SEC² , MAX VEL = 0.38 CM/SEC , MAX DISP = 0.07 CM

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
BALL MOUNTAIN DAM CREST
T-COMPONENT 300 DEG

MAX ACCE = 15.20 CM/S/S , MAX VEL = 0.33 CMS/SEC , MAX DISP = 0.08 CMS

NEW HAMPSHIRE EQKE
1/18/82.19.14.42 EST
WHITE RIVER JCT. BASEMENT
L-COMPONENT 270 DEG

MAX ACCE = 21.81 CM/S/S , MAX VEL = 0.38 CMS/SEC , MAX DISP = 0.08 CMS

NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
WHITE RIVER JCT. BASEMENT
V-COMPONENT UP

MAX ACCE = 31.00 CM/S/S , MAX VEL = 0.57 CMS/SEC , MAX DISP = 0.12 CMS
NEW HAMPSHIRE EQKE
1/18/82, 19.14.42 EST
WHITE RIVER JCT. BASEMENT
T-COMPONENT 180 DEG

APPENDIX C: NUMERICAL TABULATION OF ACCELERATION VALUES

NOTE: These numerical acceleration values can be obtained in tape format from the World Data Center A for Solid Earth Geophysics and the National Geophysical and Solar-Terrestrial Data Center (NGSDC). The address is listed below:

EDIS/NOAA
National Geophysical Data Center (D622)
Boulder, CO 80303
(303) 497-6764
FTS 320-6764